WELDING

FUNDAMENTAL PRINCIPLES AND PRACTICES

CWB

CANADIAN WELDING BUREAU

WELDING FUNDAMENTAL PRINCIPLES AND PRACTICES

Please read carefully these -

INSTRUCTIONS TO STUDENTS

This is your welding course. We hope you will find the lessons and exercises interesting and valuable to you in your work. The course has been simply written. You will not find it difficult if you study it lesson by lesson and do the exercises applicable to each as they are sent.

EXERCISES

An exercise is mailed in duplicate approximately every two weeks together with a stapled (i.e. concealed) answer sheet.

Students are advised to complete both exercise sheets in ink and then immediately refer to the answer sheet to check their answers. This procedure, according to recent training theory, serves to consolidate the correct answer in their minds. Where an answer is wrong the student should re-write the question together with the correct answer several times.

One copy of each completed exercise should be mailed at once and certainly before the return date noted thereon to the Bureau so that your progress may be judged and helped if possible.

The answer to each question will be found in the corresponding lesson and the prime purpose of the questions is to ensure that you read and re-read the lesson in order to determine the correct answers. Although discussion of the lessons with your associates is desirable - if you have that opportunity - we suggest that, in your own interests, you alone should complete the exercises.

Should your final examination marks be slightly below a pass standard, your exercises will be reviewed and may, if adequate, serve to justify a passing standard and diploma in the opinion of the examiners.

It is important that your exercises be returned by the due date or an extension of time requested from the Bureau.

It is also imperative for the continued receipt of exercises that you notify us promptly of any change of address.

CANADIAN WELDING BUREAU
1393 Yonge Street
Toronto 7, Ontario

PREFACE

We are fortunate individuals who, either by design or chance, are in the welding industry. Many of us have risen with it; many will continue to do so, and many more will follow. Welding has had a phenomenal growth, which continues more soundly and more surely year by year. Opportunity for advancement exists and will continue perhaps to a greater extent than in any other phase of industry; opportunity unlimited for all - the apprentice, the operator, the draughtsman-designer, the engineer or the man who aspires to operate his own business. The simplicity of welding and the low cost of equipment has already given many the opportunity of working for themselves; of being their own boss.

The practice of welding has been called an art; an art because it requires the co-ordination of mind and muscle and because some exhibit more aptitude than others. Almost anyone can weld and weld adequately to meet normal commercial requirements but, like all forms of art, welding has its superlative artists. Like any art giving latitude to its proponents it has its own fascination, - the fascination of skill and of achievement. It stirs the imagination to think that the arc welding operator has literally at his fingertips the control of 10-20 H.P.- energy of this magnitude being directed at his will from the end of a tiny wire electrode. Further, that he is practising the art of steel making, of casting, and of joining involving all the chemical, metallurgical and mechanical operations connected therewith.

To the engineer. . .the draughtsman-designer. . .welding issues a challenge; a challenge to better the past, the challenge of progress and achievement; to accomplish what has not before been accomplished; to advance by original thinking to new designs and better products. Welding provides industry with a new tool, holding forth possibilities to improve on past designs, to supersede castings and eliminate riveting.

Both castings and riveting benefit by years, even centuries of experience. Welding has but few such years in comparison and yet it has superseded many products so made. A few more years relatively and it will largely replace such methods if the imagination, the energy and the ingenuity of engineers is given full play and opportunity. Some inertia still exists; tradition still retards progress, but the transition is sure. It is only

the pace that is in question and for that we are responsible. Welding has been presented to us. It is inherently sound; inherently better, and inherently more economical if used correctly.

This course of lessons and exercises is dedicated to such progress and to the advancement of all those who participate in them.

INTRODUCTION

The prime purpose of this series of lessons and accompanying exercises is to instruct arc welding supervisors and present them with the basic fundamental principles and practices of Sound, Safe welding carried out on a commercially economical basis.

It was originally conceived and is presented as a course of instruction for the Supervisors of Fabricators desiring approval to the requirements of the Canadian Standards Association Welding Qualification Code W47. To be approved in accordance with the requirements of this code, Fabricators must employ adequately qualified and trained supervisory and engineering personnel.

However, it has been made generally available because it is felt that not only will it be of value to supervisors of all welding firms but equally to all draughtsmen-designers and engineers who deal with or may deal with welding and, in addition, to those operators who wish to be qualified for supervisory positions.

Certainly what is known about welding by the supervisor should be known by the draughtsman-designer if he is both to design and specify shop practices and procedures intelligently and efficiently. Further an engineer cannot truly qualify as a welding engineer unless in addition to his engineering training he possesses the knowledge both of the welding designer and supervisor.

Accordingly, this series, although planned originally for the supervisor, is considered as being equally valuable to the operator, the inspector, the draughtsman-designer and the engineer.

Its prime purpose however should not be lost sight of and it must be recognized that it cannot become a compendium of all welding knowledge. Neither is it intended to be original. It aims to bring under one series in a simple, straight forward manner that information which is most likely to be of most importance to the average supervisor, in the shops of the average Canadian fabricator. This leaves out much, but this can be included if desired by supplementary reading suggested by biblio-

graphies appended to certain lessons. On the other hand, it includes a great deal and must do so for the simple reason that the supervisor in the average Canadian plant is to all intents and purposes the welding engineer. Few plants can afford the latter.

Consequently the supervisor is a man of importance. He carries considerable responsibility and is expected to have all the answers with respect to welding, whether it be choice of processes and equipment, electrodes, steel, design, standards, procedures, jigs and fixtures, plant flow and layout, operator tests, wage incentives and inspection. Much has been published and much more can be written on all these aspects and most is of interest and much of value. However, too much can be confusing and tend to obscure the important. This course attempts to select the latter only and to present it clearly and concisely without superfluity or any attempt on the part of the authors to exhibit the sum total of their knowledge.

Written for the many, some parts will inevitably be elementary to some. Parts also will be more applicable to one industry than another industry. All should nevertheless be useful and make for an all around competent arc welding supervisor or a better qualified draughtsman-designer and engineer.

CANADIAN WELDING BUREAU.

LESSON 1

BASIC JOINTS AND WELD TYPES

Welding consists of joining two or more pieces of metal by the application of heat and sometimes pressure. In arc welding the heat comes from an electric arc and no pressure is employed to fuse the metal parts. Sometimes the heat from the arc is used to melt and fuse the parts together without adding extra metal. In most applications of arc welding, however, molten metal is added to the joint and usually this joint is specially prepared like a mould to receive such metal.

Since welding is a joining process the student should first have a knowledge of the joints themselves, what they look like, what they are called, how they are prepared and what are their uses and limitations; likewise the various types of welds used to make these joints are equally important.

Not only must the names of these joints and welds be familiar but also the symbols by which each is designated. These symbols are a form of shorthand by which the drawing office indicates how joints are prepared and welded. The shop must be as familiar as the drawing office with symbols in order to arrive at the correct interpretation.

These symbols will be studied throughout the entire course and this first lesson is in part designed to prepare the student for such study by familiarizing him with the common types of joints, and welds used for the purpose of making these joints.

FIVE BASIC JOINTS

There are only five basic joints, although many variations of these result from the manner of preparation and assembly. These five, illustrated herewith, are termed butt joint, corner joint, Tee joint, lap joint and edge joint.

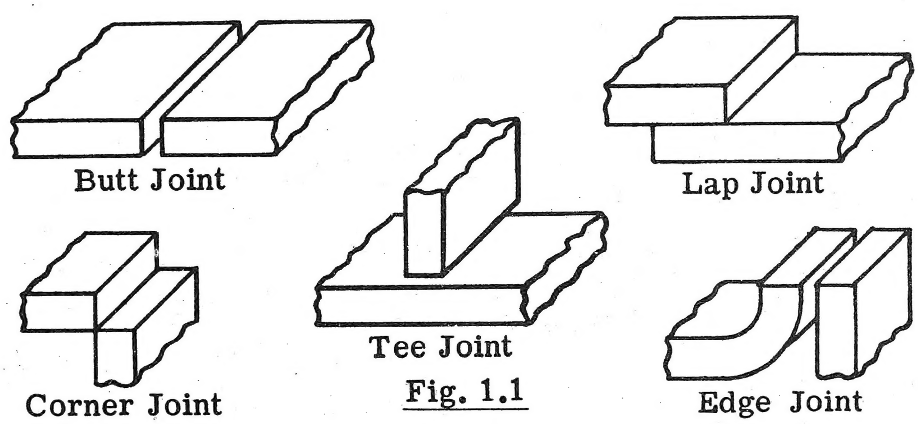
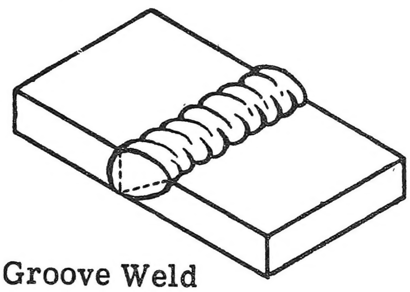


Fig. 1.1

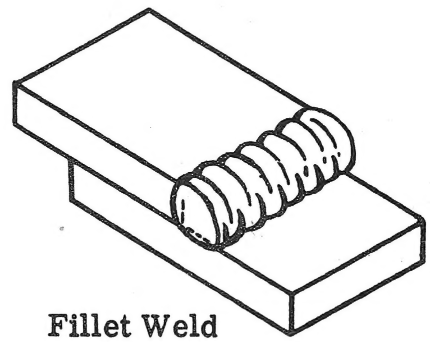
THREE BASIC WELDS

There are only three basic welds. They are groove, fillet and plug. These terms are somewhat descriptive of the joint and the weld. Many variations are possible.

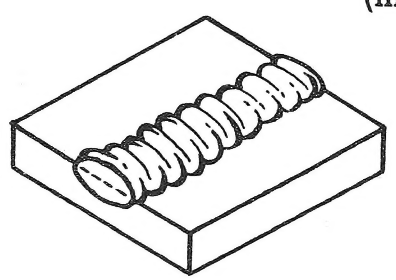
All welds are composed of one or more beads. A bead is a single run or pass of weld metal. A bead or beads may be used to build up a surface and need not necessarily be used for making a joint. When it is so used to 'build up', 'layer' or 'butter' a surface it may be termed a 'bead weld' thus making, in a sense, a fourth type.



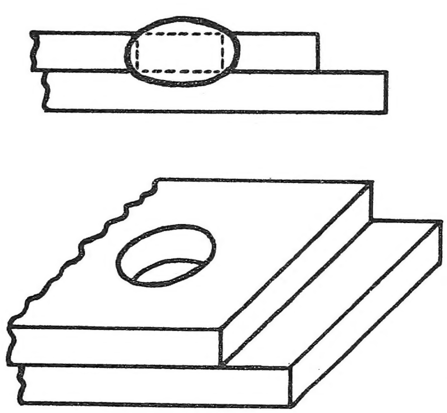
Groove Weld
(making butt joints)



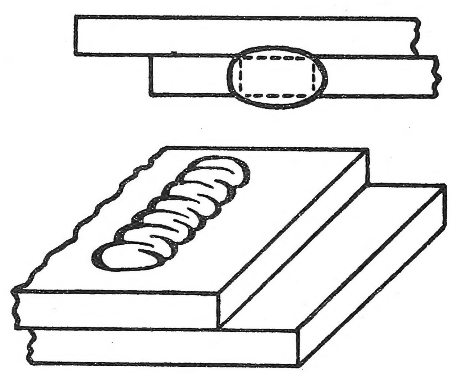
Fillet Weld
(making lap joint)



Bead Weld



Plug or Rivet Weld
(making lap joint)



Slot Weld - variant of Plug Weld
(making lap joint)

Fig. 1.2

GROOVE WELDS

As the name implies, the joints for such welds are in some manner prepared to form a groove or crucible to receive the weld bead or beads. There are five types - square groove, V-groove, bevel groove, U-groove and J-groove.

These illustrations of the various types of groove welds are all shown as applying to butt joints. Some or all of these welds are applicable also to corner joints, Tee joints, lap joints and edge joints.

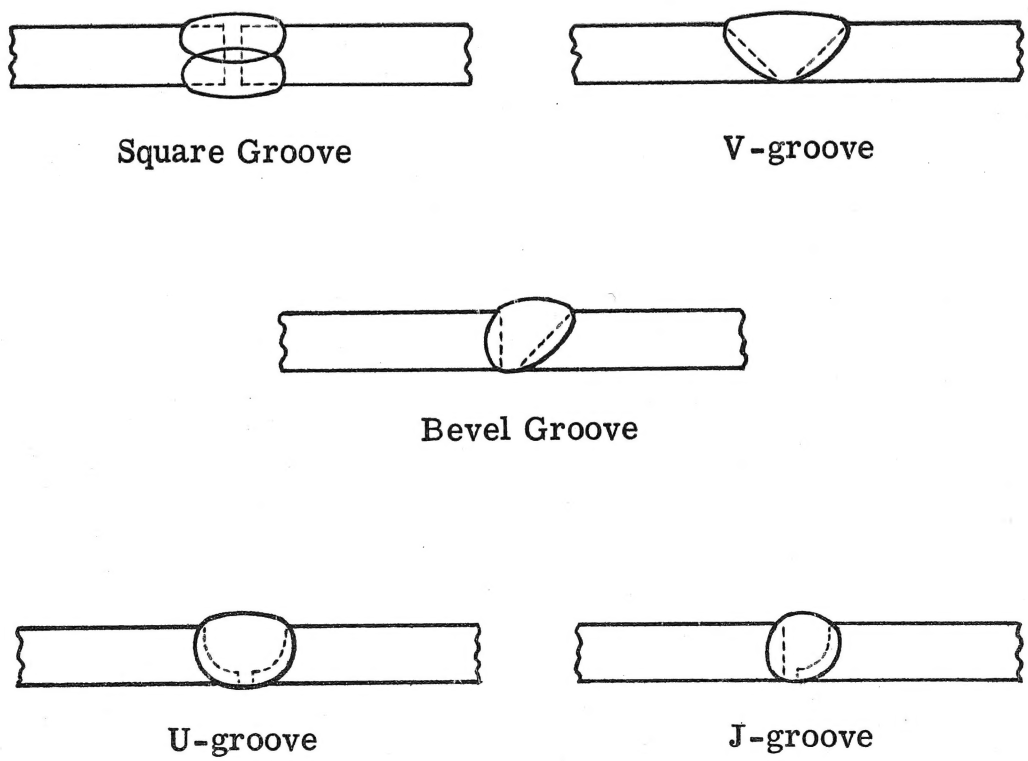


Fig. 1.3

NOTE:- These joints are permitted unrestricted use provided root of weld is chipped out to sound metal before opposite side of joint is welded, with the exception of the Bevel and J-grooves in some positions of welding where access to the joint is limited.

Joint and Weld Nomenclature or Terms

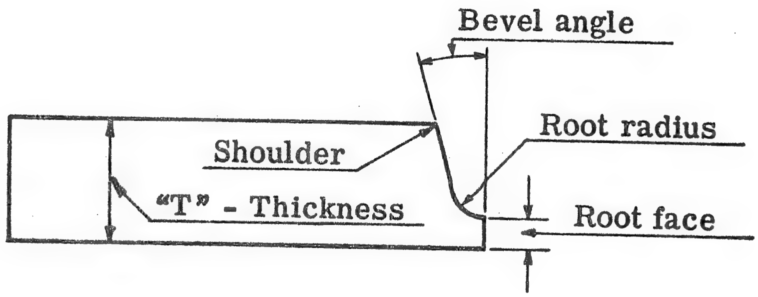


Fig. 1.4

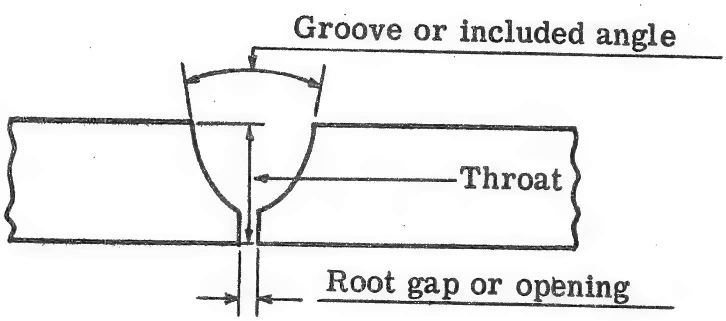


Fig. 1.5

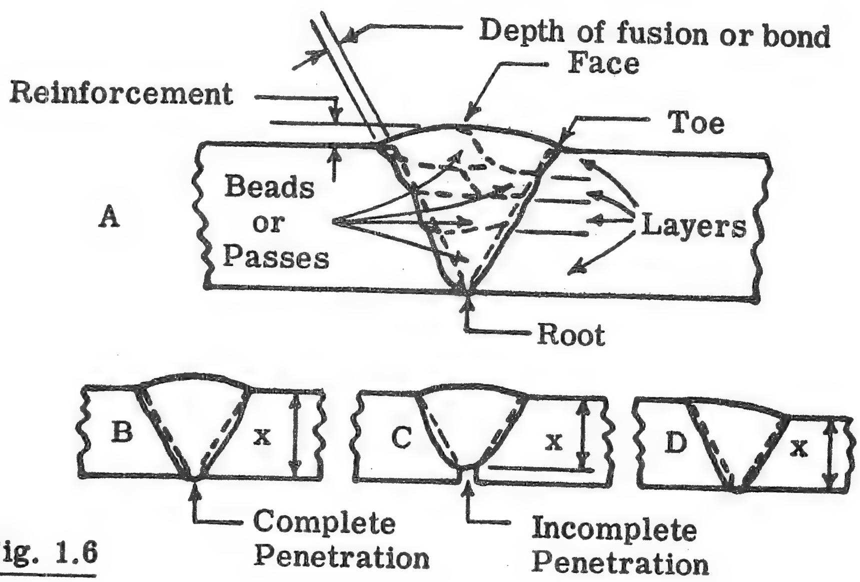


Fig. 1.6

NOTE: - the weld size (x) is defined in sketches B, C, and D., Where penetration is complete as at B the weld size is the thickness of the plate. Where penetration is incomplete as at C, the weld size is the depth of fusion, Where the plates differ in thickness as at D and penetration is complete the weld size is the thickness of the thinner plate.

Joint Dimensions

To ensure sound welding, joints should be so designed and dimensioned that the operator will have adequate access with the proper sized electrode in the correct welding position. This requires certain bevels on plate edges and certain gaps between plates or sections as well as freedom from near by obstructions. The preparation and dimensions will also vary in accordance with the thickness of the material being welded and whether a perfect joint efficiency is required for the service conditions.

Thus a butt joint may be prepared and welded in many ways such as:

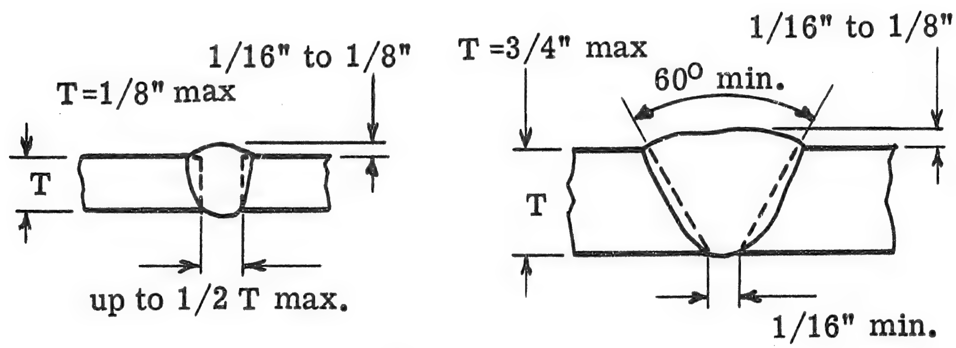
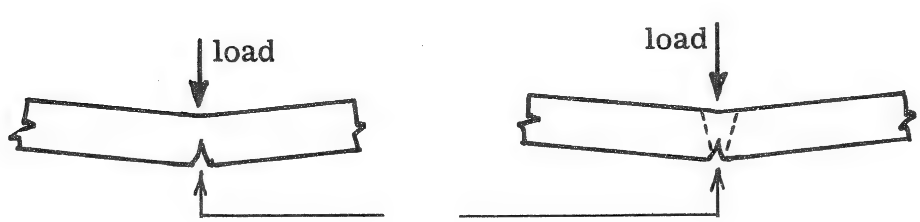


Fig. 1.7

NOTE: -

The allowable working strength of joints welded from one side only is restricted to 50% of that allowed for joints welded from both sides, or with a suitable backing bar. Moreover, this type of joint must not be used when the root is likely to be subjected to tension bending as shown below.



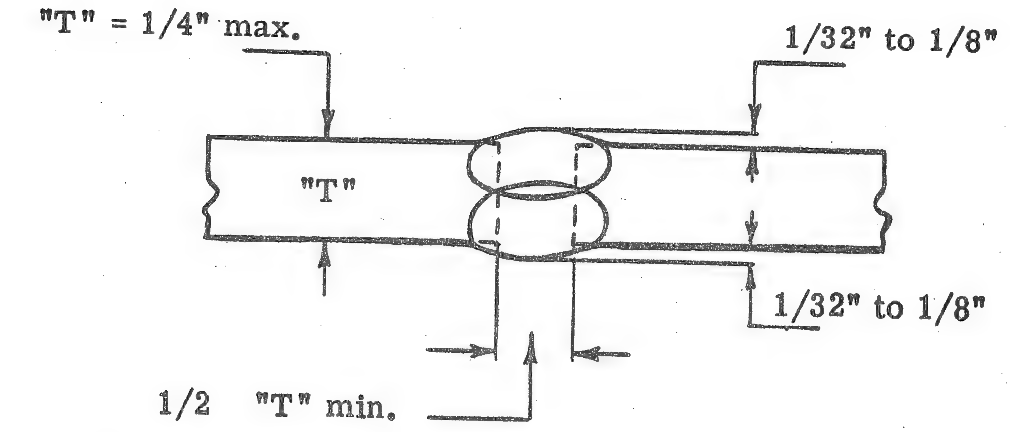


Fig. 1.8 - Square Groove Open Butt Joint welded with bead weld from both sides.

NOTE: - Unrestricted use - provided root of weld shall be chipped or gouged out to sound metal before opposite side of joint is welded.

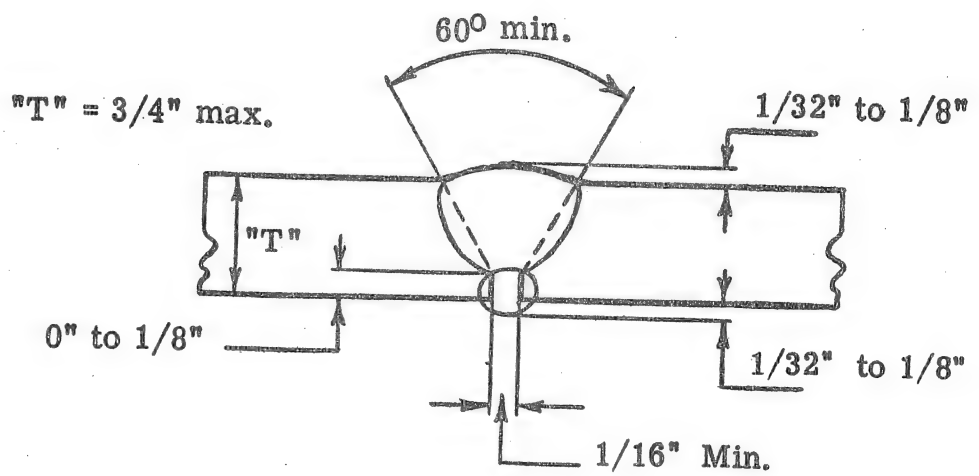
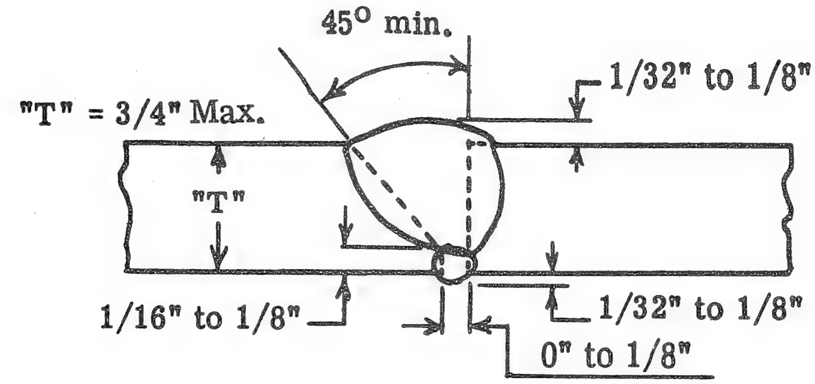


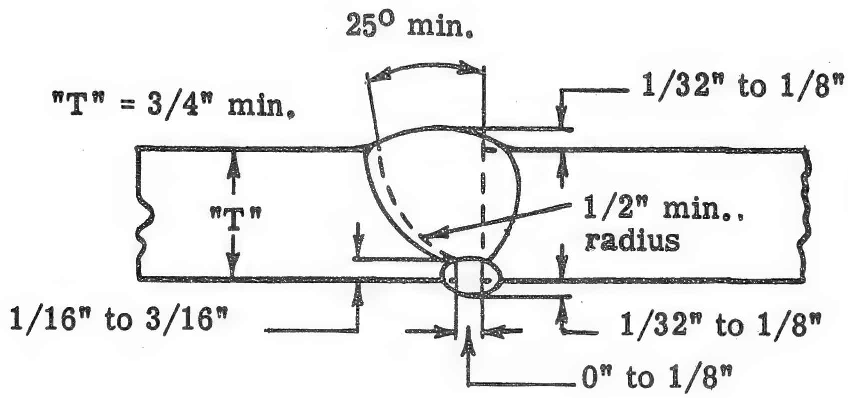
Fig. 1.9 - Single V-Groove Weld welded both sides.

NOTE: - Unrestricted use - provided root of weld shall be chipped or gouged out to sound metal before opposite side of joint is welded.



T = 3/4" Max. is normal but may be less.

Fig. 1.10 - Bevel groove welded from both sides



T = 3/4" Min. is normal but may be more.

Fig. 1.11 - J-Groove Weld welded both sides.

NOTE: - Unrestricted use - for both Bevel-groove and J-groove welds - provided root of weld shall be chipped out to sound metal before opposite side of joint is welded.

When these joints are used in the flat and overhead positions of welding no obstruction shall be closer than 6" to the edge of the bevelled plate.

When these joints are used in the horizontal or vertical positions of welding no obstruction shall be closer than 18" to the edge of the bevelled plate.

The joints as shown shall be used in the flat and overhead positions only.

When used in the horizontal and vertical positions the included angle shall not be less than 45° for Fig. 1.11.

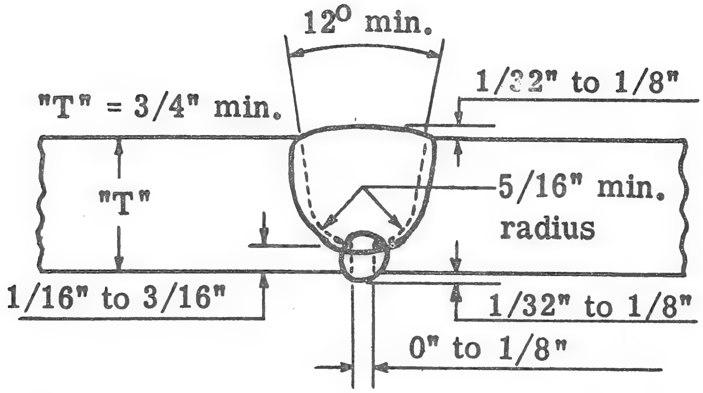


Fig. 1.12 - U-groove welded from both sides.

NOTE: - Unrestricted use provided root of weld is chipped or gouged out to sound metal before opposite side of joint is welded.

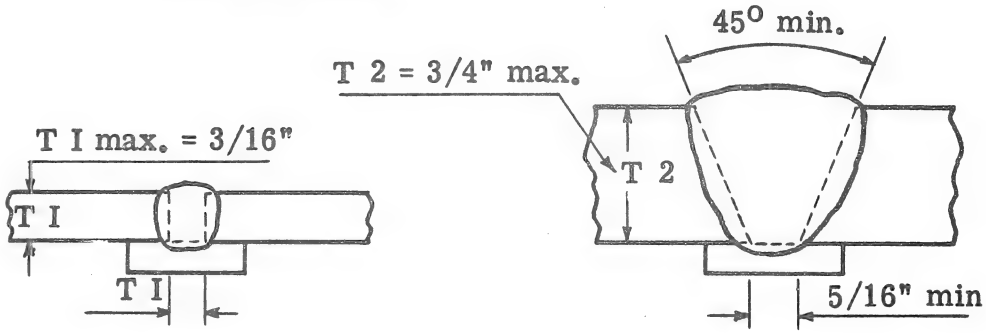


Fig. 1.13 - Butt Joints with Backing Strips

When it is impossible or undesirable economically to weld butt joints from both sides, backing strips or bars may be used to permit a full and even penetration of the weld through the joint.

NOTE: - Unrestricted use - provided procedure specification tests have been approved and recorded.

The dimensions for joint design and welding instructions must be carefully conveyed to the shop staff by means of standard sheets or product drawings. A cross section view of unusual joint and weld combinations may be necessary or the standard welding symbols (lesson 2) may suffice.

FILLET WELDS

This term is given to welds making lap, tee joints or inside corner joints. Such welds may consist of one or more beads or layers and are approximately triangular in cross section; they join two surfaces approximately at right angles to each other in the above mentioned joints.

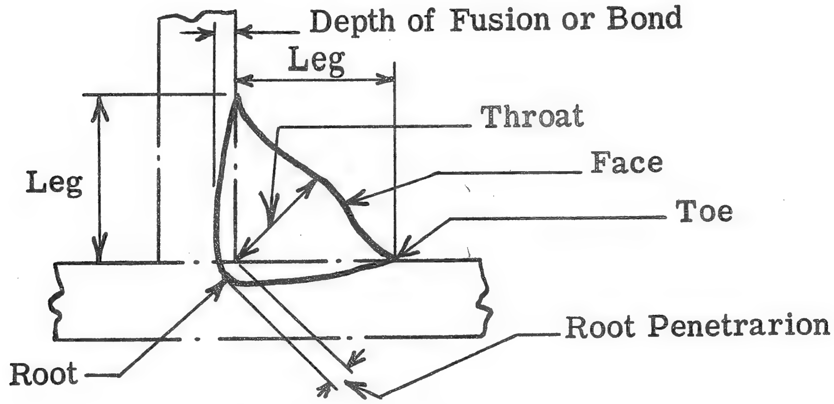


Fig. 1.14 - Ideal Fillet Weld Shape

As will be noted in Fig. 1.14, the ideal fillet weld is one where the joint faces are at 90^{o}, the weld has equal legs, the face is flat or slightly convex and the toes merge smoothly with the surfaces of the joint members.

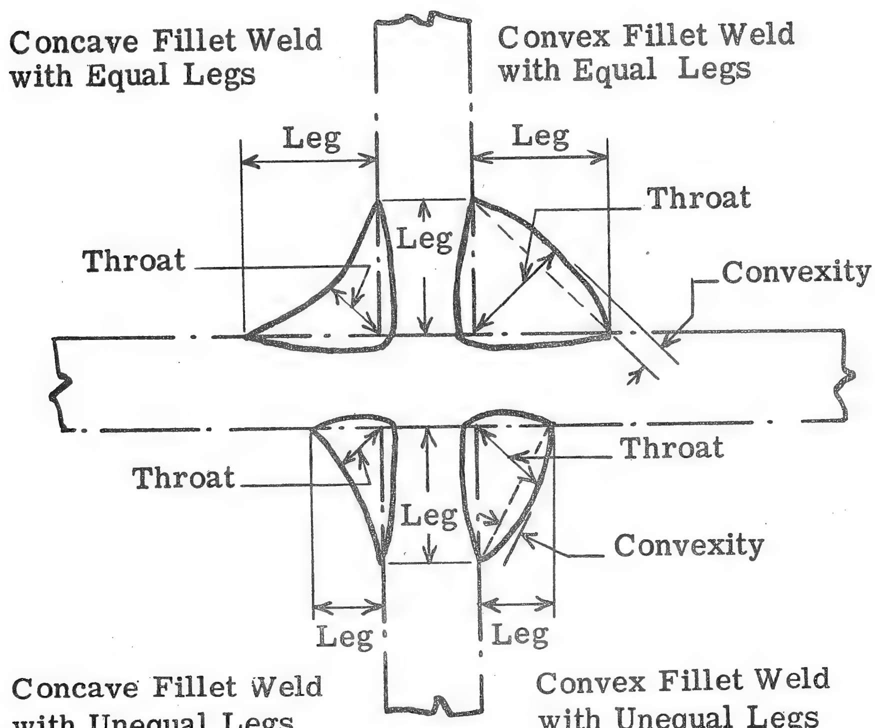


Fig. 1.15

Dimensions

The size of a fillet weld is determined by the leg length of the largest equal leg triangle that can be drawn within the cross section of the weld. The strength of a fillet weld is calculated from its throat dimension which, as can be noted in Figs. 1.16 and 1.17 may be the theoretical throat in some cases, and the actual throat in others.

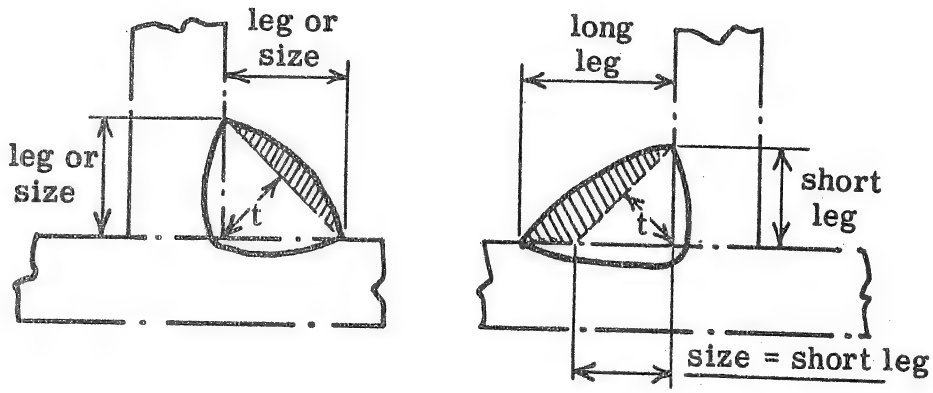


Fig. 1.16 - Convex Fillets

For convex fillets, shown in Fig. 1.16, the size is obtained by measuring the shortest leg; the resulting throat dimension " t " on which the strength is calculated is 0.7 times the size. It can readily be seen that any metal lying outside the equal leg triangle is wasteful since it is not considered to add to the size or strength of the weld. Excessively convex or unequal leg fillet welds are therefore undesirable.

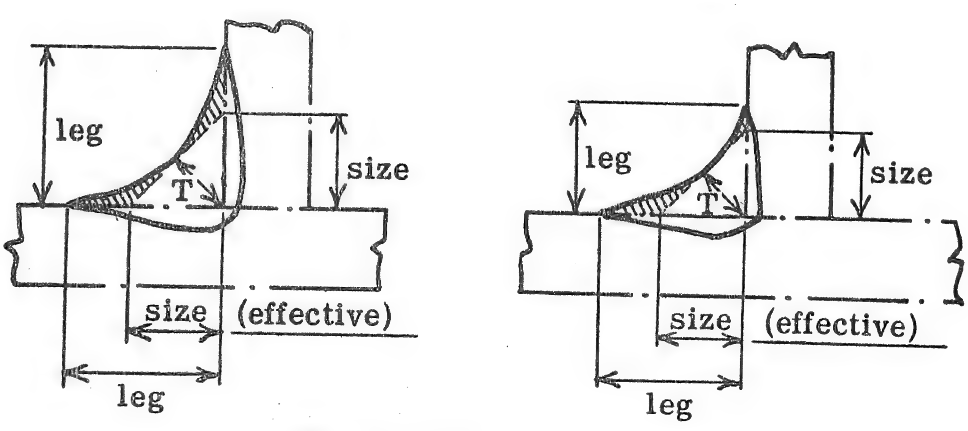


Fig. 1.17 - Concave Fillets

For concave fillets, shown in Fig. 1.17, the size is not obtained by measuring the leg length. Instead, the actual throat "T" is measured and the "effective" leg length or size will be 1.4 times "T". Again it will be noted that metal lying outside of the resulting equal leg triangle is wasteful and unnecessary so that unequal or excessively concave fillet welds are undesirable.

PLUG WELDS

A descriptive term for this weld is rivet weld. They are employed chiefly for lap joints but may be used for Tee joints on thick plate where a fillet weld is not adequate or is not possible due to inaccessibility. When a slot is made rather than a circular hole the weld is called a slot weld. It is a form of plug weld.

In all cases a hole or slot is punched, drilled or flame cut in one plate and a weld made through it to the underlying plate joining the two by a fillet weld around the periphery of the hole or slot. The hole or slot may or may not be entirely filled in with weld metal.

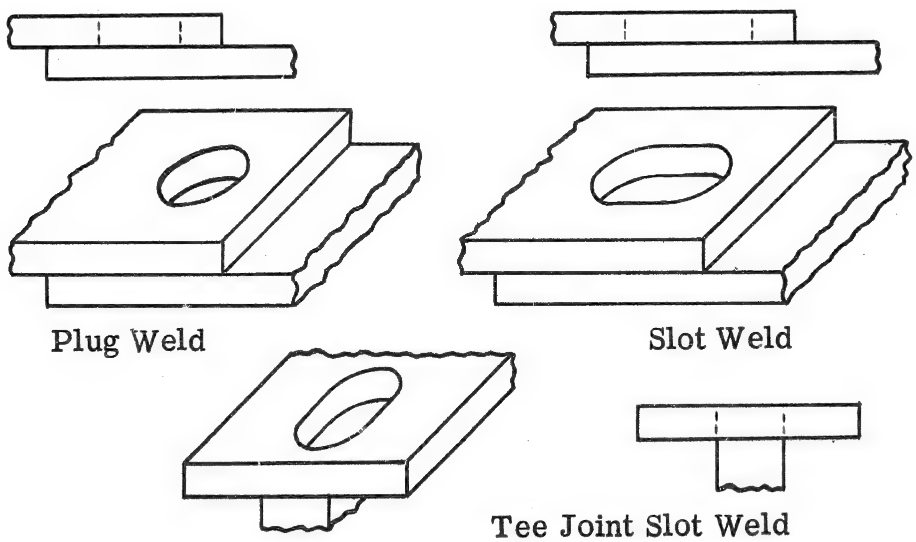


Fig. 1.18 - Plug and Slot Welds

TACK WELDS

These are short, sometimes temporary, welds used to assemble parts and hold them in alignment for final welding. They are spaced at intervals along a joint and usually consist of only one bead.

CONTINUOUS WELDS

Welds that continue without break throughout the length of a joint are called continuous welds. Welds are made continuous unless otherwise specified.

INTERMITTENT WELDS

Such welds are short welds usually of equal length (2" to 12" generally) spaced at equal intervals along a joint. They may consist of one or more beads.

POSITIONS OF WELDS

With metallic arc welding it is possible to deposit metal in any position so that an operator may make a joint that is below him, in front of him, above him, or at any intermediate position between these three.

A weld is said to be made in the flat position, horizontal position, vertical position or overhead position depending on the position of the joint in relation to the floor. Welding techniques for the four positions of welding vary according to the ease of depositing metal. It is possible to deposit weld layers of considerable volume in the flat and vertical positions, but stringer beads are normally used for horizontal and overhead welding. These positions are better illustrated than described, and are shown in Fig. 1.19 for groove welds and fillet welds on a tee joint.

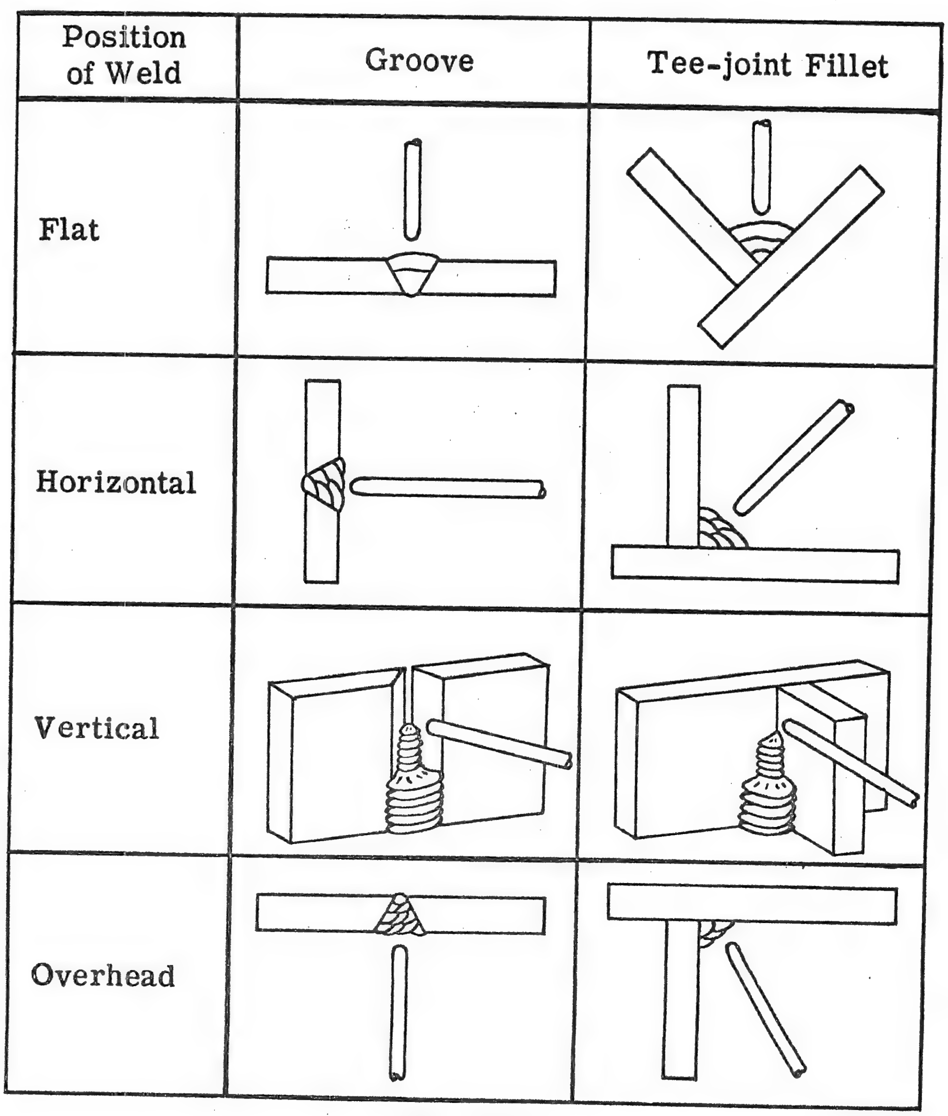


Fig. 1.19

EXERCISE 1 - LESSON 1

WELDING FUNDAMENTAL PRINCIPLES AND PRACTICES

1. What is the actual size of an equal legged concave fillet weld whose throat dimension is 3/4"?

   1.05"

2. (a) What is the usual root opening for a square edge butt joint in terms of 'T', the thickness of the plates being joined?

   0.5 T

   (b) Should this root opening be greater or less than normal if a backing bar is being used?

   GREATER

3. Throat dimension of one convex fillet weld is 3/8" and of another is 1/2" but both have the same leg dimensions. Is the one with the thicker throat considered stronger?

   NO

4. Name the three basic welds:

   GROOVE FILLET PLUG

5. Illustrate, by a sketch of a groove weld or welds, the difference between a 'pass' and a 'layer' of weld:

6. In preparing groove joints for welding, what is generally recommended as:

   (a) Minimum angle of bevel in a V-groove? 60°

   (b) Minimum angle of bevel in a bevel-groove? 45°

   (c) Minimum root opening in a V-groove? 1/16"

   (d) Maximum root face in a V- or bevel-groove? 1/8"

(Over)

EXERCISE 1 - LESSON 1 (Continued)

7. Name the five basic joints:

   BUTT, LAP, TEE, EDGE, CORNER

8. (a) Name the three types of faces that fillet welds may have:

   CONCAVE EQUAL Leg, CONVEX EQUAL LEG, CONCAVE or CONVEX UNEQUAL LEG

   (b) In the same order as your answers in (a), state what you would measure to obtain the size of these welds:

   THROAT, LEG, SHORTEST LEG.

9. What is the 'size' of a groove weld between a 3/4" plate and a 1" plate?

   3/4"

10. What is the 'size' of a convex fillet weld having one 5/16" leg and one 7/16" leg?

    7/32"

11. Draw a sketch of a flat fillet weld:

12. Name and sketch five different kinds of groove welds:

SQUARE GROOVE, V-, BEVEL, J, U

13. What is your name? [redacted]

    and address?

RETURN THIS EXERCISE BEFORE AS SOON AS POSSIBLE

Canadian Welding Bureau
1393 Yonge Street
Toronto - Ontario

ANSWERS TO EXERCISE 1 - LESSON 1

WELDING FUNDAMENTAL PRINCIPLES AND PRACTICES

1. 1.05 inches (1 inch considered correct).

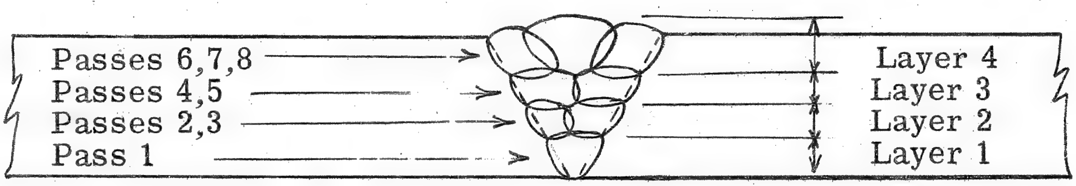
2.(a) 1/2 T

(b) Greater

3. No

4. groove; fillet; plug

5.



6.(a) 60°

(b) 45°

(c) 1/16"

(d) 1/8"

7. butt; lap; corner; tee; edge

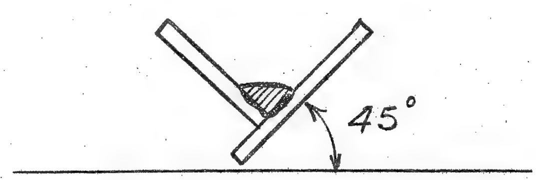
8.(a) concave; convex; flat

(b) throat; leg; leg or throat

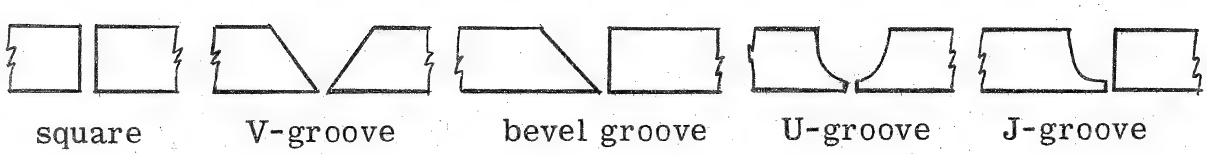
9. 3/4"

10. 5/16

11.



12.



Canadian Welding Bureau
1393 Yonge Street
Toronto - Ontario

LESSON 2

BLUEPRINT READING AND STANDARD WELDING SYMBOLS

The section of this lesson on blueprint reading is brief and deals only with how to read lines and understand the relationship of the views shown on a drawing. Its prime purpose is to acquaint the student with the principles used in making and interpreting the standard welding symbols described in the other section of this lesson. Therefore, unless the student is already familiar with drawings and blueprint reading, he should study this section before going on to symbols and later lessons.

On the other hand, the section dealing with welding symbols is very complete and in detail. However, the student is <u>NOT</u> expected to master them completely before proceeding with later lessons. Instead, symbol exercises will be sent out from time to time (the first such one with this lesson) and a note at the beginning of each exercise will outline the material to be studied on symbols before completing the exercise.

With this planned program of study, it is expected that the student will, in easy stages, become thoroughly familiar with the use of welding symbols by the time the course has been completed.

BLUEPRINT READING

Of all the means to convey design instructions from the Engineering Department to the shop, drawings are by far the most frequently used.

A drawing is a means of communication. It conveys information to the shop and provides a permanent record. It conveys specific information, putting the engineer's designs in such form that the various component parts of a machine or piece of apparatus can be manufactured and assembled correctly. Drawings also furnish the customer with the information necessary to install the apparatus and to enable the manufacturer to provide duplicate parts.

It is important then that the men in the shop interpret these drawings correctly in order to produce the desired part, true to size and shape. To interpret a drawing it is necessary to understand the meaning of the lines, signs and symbols used by the engineer and draughtsman in making the drawing.

LINES AND THEIR USES

Visible outline	Heavy solid line to indicate edge
Hidden edge or outline	Light, short dashes
Dimension line	Thin, solid line and arrows
Extension line	Thin solid line
Centre line	Thin, long and short dash
Dimension line with reference or extension lines	Light lines indicating limits of dimension
Section or cutting plane line	Heavy, long and short dashes
Cross-hatching lines	Thin, sloping lines
Broken section line	Full line with freehand breaks

Visible outlines are full bold lines used to indicate the outline or edge of part that can actually be seen. They are the heaviest lines on the drawing.

Hidden outlines are light dashes and are used to indicate edges that cannot be seen from this view.

Dimension lines with arrowheads indicate the limits of dimension and when used outside the visible outline, point to a reference line which extends from the edge of the part.

Broken section lines are used to indicate no change in detail where there is not enough room to show the complete section.

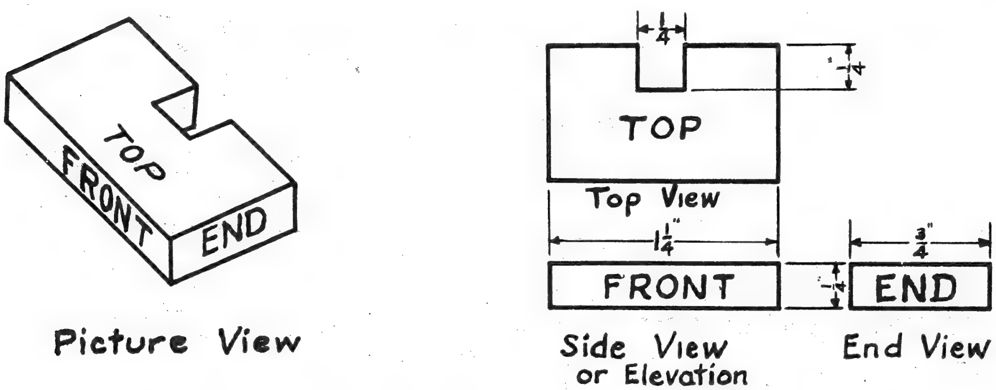
To read a drawing first of all study the heavy lines and become familiar with the general shape and outline. Then study the hidden outlines for the outside or other side of the object. Following this, note the dimension lines and study the size of its parts, location of holes, pads, brackets, etc.

DESCRIPTION OF SHAPE

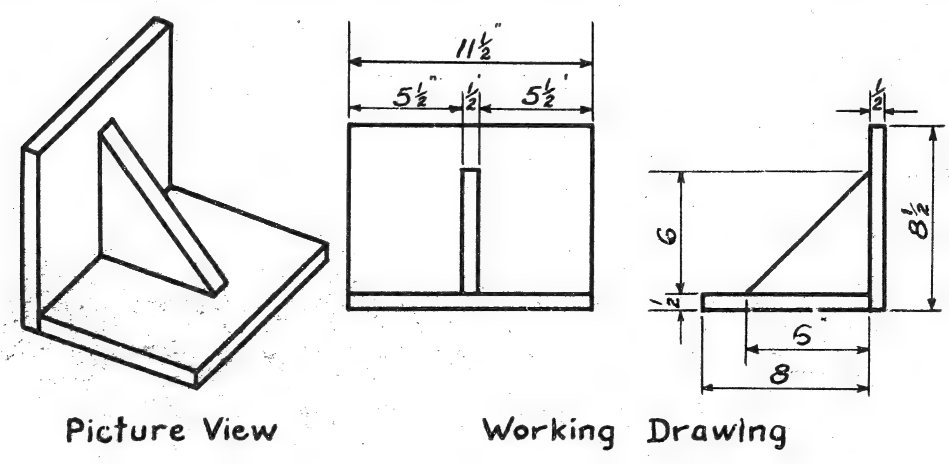
Working drawings are drawings which show the correct shape and size of an object. The shape of an object can be seen correctly by viewing the object from different positions.

On examining a drawing you will notice two or more views, depending on the shape of the part These views have a specific relationship to each other. In detailing a part we can readily understand that the objects have three dimensions; namely, length, height and depth.

In order to show these three dimensions, we have to show views taken from different positions. In the sketch below, the picture view shows the shape of the part, but this type of drawing is difficult to dimension, so that working drawings are made to show only two dimensions on one view, i.e. length and height, or width and height, or length and width. Thus it is general to show three views of the object in order to give all the dimensions clearly.

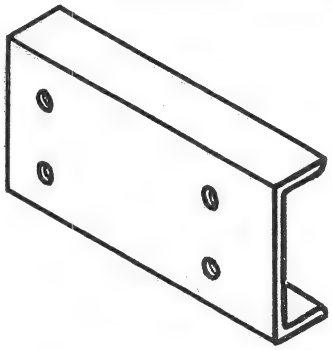


At times it may be necessary to show only two views of the object if all dimensions can be shown or clearly given, thus·

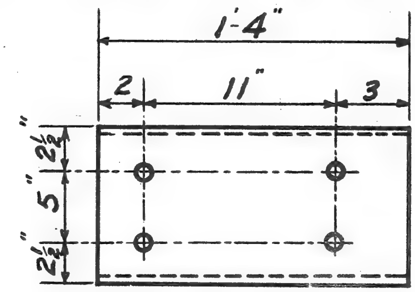


INVISIBLE EDGES

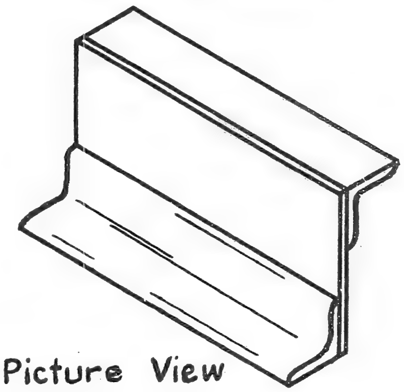
For some parts there are edges which may be seen in one view as a visible edge, but in other views as a hidden edge. This quite often indicates the direction of flanged edges and structural shapes as shown below.



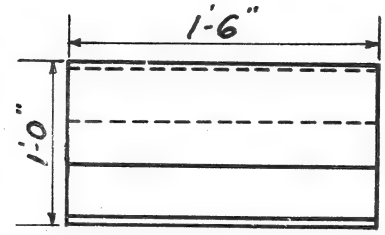
Picture View



Front View or Elevation
This view shows the hidden edge indicating flange of channel is away from reader.



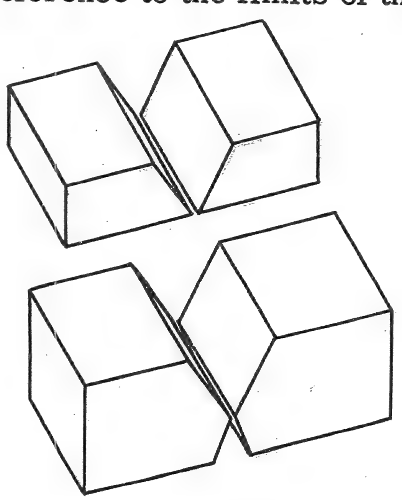
Picture View

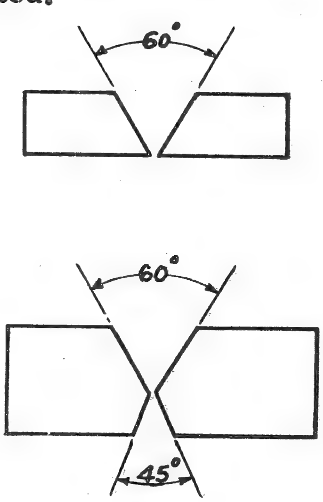


Front View or Elevation
This view shows hidden edges indicating one angle is on side of plate away from reader.

ANGLE DIMENSIONS

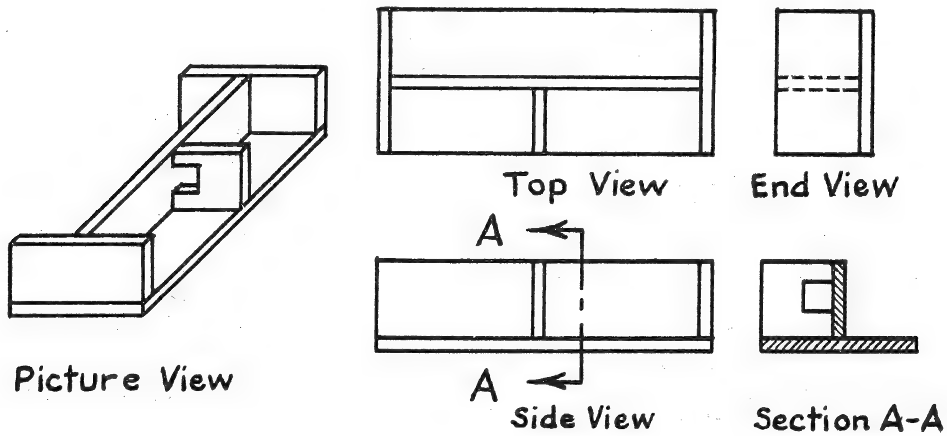
The drawing below shows the measurement of angles in degrees, with curved dimension lines, and extension lines having reference to the limits of the angles indicated.

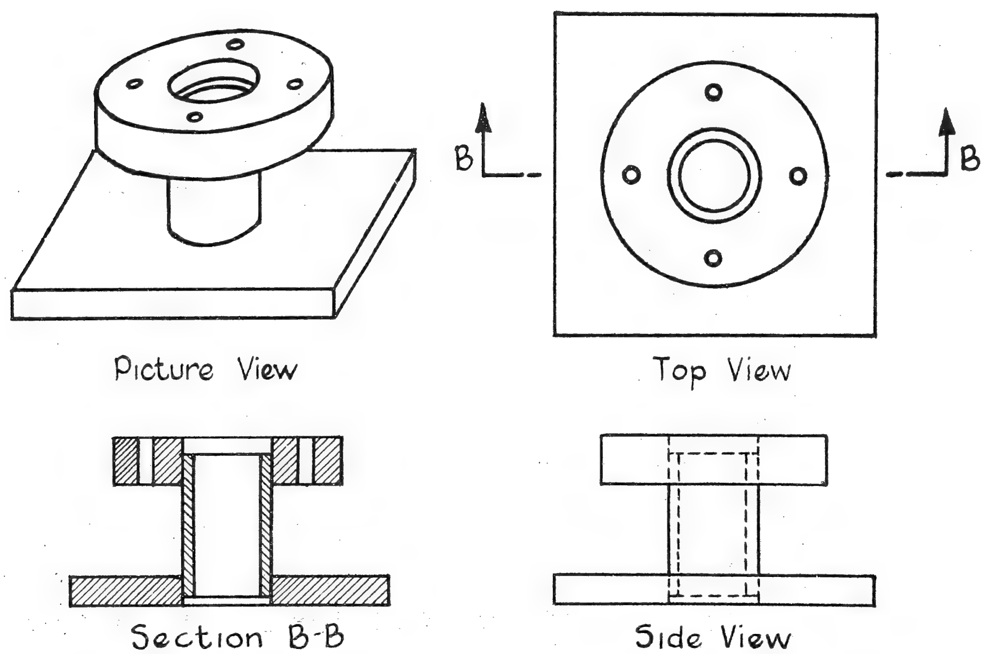




CROSS SECTIONS

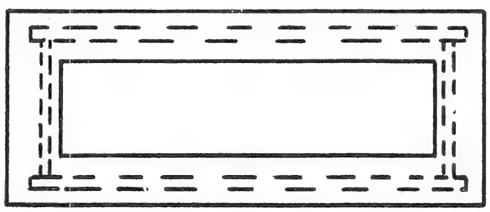
Cross sectional views, generally called 'sections', are internal views of the object, usually drawn for the purpose of indicating some detail which cannot be shown clearly by an outside view of the object. It is as if the object has been cut in two parts along a plane or section indicated by the cross sectional lines, and all surfaces which have been so cut are shown by cross-hatching lines between the outlines of those surfaces (in contrast to end views which have no cross-hatching). Examples of this type of drawing are given below.



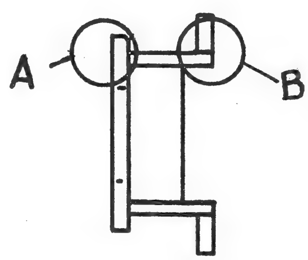


An object is usually drawn to a scale which is just large enough to show the various views required and fill a standard size sheet of drawing paper. Sometimes this scale is too small to give adequate information on some details, so that these details may be drawn to a larger scale, or even full size, in order to indicate clearly how the part is to be made.

Where such details indicate the preparation and welding of the parts, the completed welds, if drawn, are usually shown by indicating the final shape of the weld in full, bold outlines and the prepared and welded edges of the plate in dotted lines. However, if only the preparation of the plate is to be shown, then full lines are used to indicate the shape of the part before the weld is made. Examples are shown below.

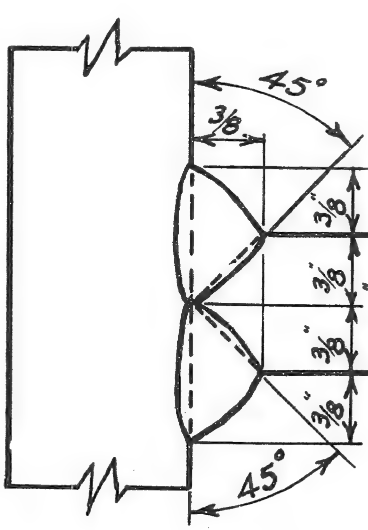


Plan V ew

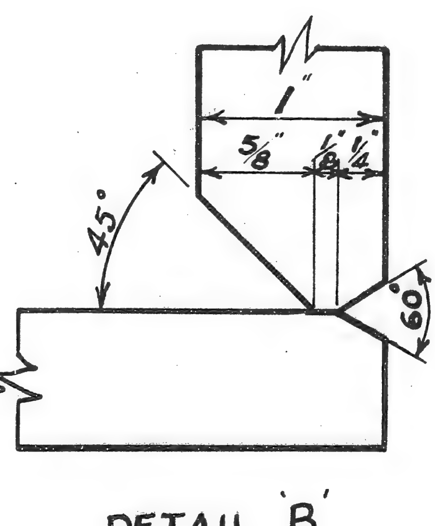


End View

Elevation



DETAIL A
Scale - full size
Showing Completed Weld



DETAIL 'B'
Scale - full size
Showing Weld Preparation

**STANDARD WELDING SYMBOLS

Welding cannot take its proper place as an engineering tool unless means are provided for conveying the information from the designer to the workmen. Such practices as writing "To be welded throughout" or "To be completely welded" on a drawing, in effect transfer the design of all attachments and connections from the designer to the welding operator, who cannot be expected to know what strength is necessary. This practice, in addition to being dangerous, may also be costly, for certain shops in their desire to be safe use much more welding than is necessary.

These symbols provide the means of placing complete welding information on drawings. In practice many companies will probably need only a few of the symbols, and if they desire, can select only such parts of the scheme as fit their needs. If this is done universally, all will be speaking the same language even though some use but a few of the symbols contained herein.

The use of the words "far side" and "near side" in the past has led to confusion because when joints are shown in section, all welds are equally distant from the reader and the words "near" and "far" are meaningless. In the present system the joint is the basis of reference. Any joint the welding of which is indicated by a symbol will always have an "arrow side" and an "other side". Accordingly, the words "arrow side", "other side" and "both sides" are used herein to locate the weld with respect to the joint.

For purposes of this course, references to Resistance welding, i.e. Spot, Seam, Projection or Flash, may be ignored.

The tail of the symbol is used for designating the welding specifications, procedures or other supplementary information to be used in the making of the weld. If a welding operator knows the size and type of weld, he has only part of the information necessary for making that weld. The process, identification of filler metal that is to be used, whether or not peening or root chipping is required, and other pertinent data must be known. The notation to be placed in the tail of the symbol indicating these data will usually be established by each user. If notations are not used, the tail of the symbol may be omitted.

**From Standard Welding Symbols, 1947, American Welding Society

SECTION I—BASIC SYMBOLS

101. Arc and Gas Weld Symbols

Arc and gas weld symbols shall be as shown in Fig. 1.

TYPE OF WELD							
BEAD	FILLET	PLUG OR SLOT	GROOVE				
			SQUARE	V	BEVEL	U	J

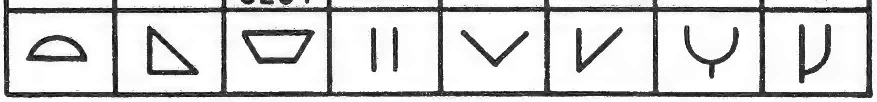


Fig. 1—Basic Arc and Gas Weld Symbols

102. Resistance Weld Symbols

Resistance weld symbols shall be as shown in Fig. 2.

TYPE OF WELD			
SPOT	PROJECTION	SEAM	FLASH OR UPSET

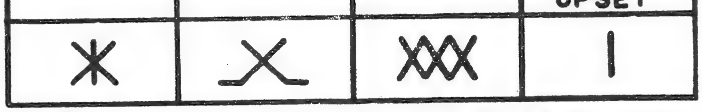


Fig. 2—Basic Resistance Weld Symbols

103. Brazing, Forge, Thermit, Induction and Flow Welding Symbols

Brazing, forge, thermit, induction and flow welding shall be indicated by using a process or specification reference in the tail of the welding symbol. (See Article 305 and Fig. 40.)

104. Supplementary Symbols

Supplementary symbols to be used in connection with weld symbols shall be as shown in Fig. 3.

WELD ALL AROUND	FIELD WELD	CONTOUR	
		FLUSH	CONVEX
○	●	—	⌒

Fig. 3—Supplementary Symbols

105. Elements of a Welding Symbol

This standard makes a distinction between the terms *weld symbol* and *welding symbol* The *weld symbol* is the ideograph used to indicate the desired type of weld. The assembled *welding symbol* consists of the following eight elements, or such of these elements as are necessary·

Reference line.
Arrow.
Basic weld symbols
Dimensions and other data.
Supplementary symbols.
Finish symbols.
Tail.
Specification, process, or other references.

106. Standard Location of Elements of a Welding Symbol

The elements of a welding symbol shall have standard locations with respect to each other as shown in Fig. 4.

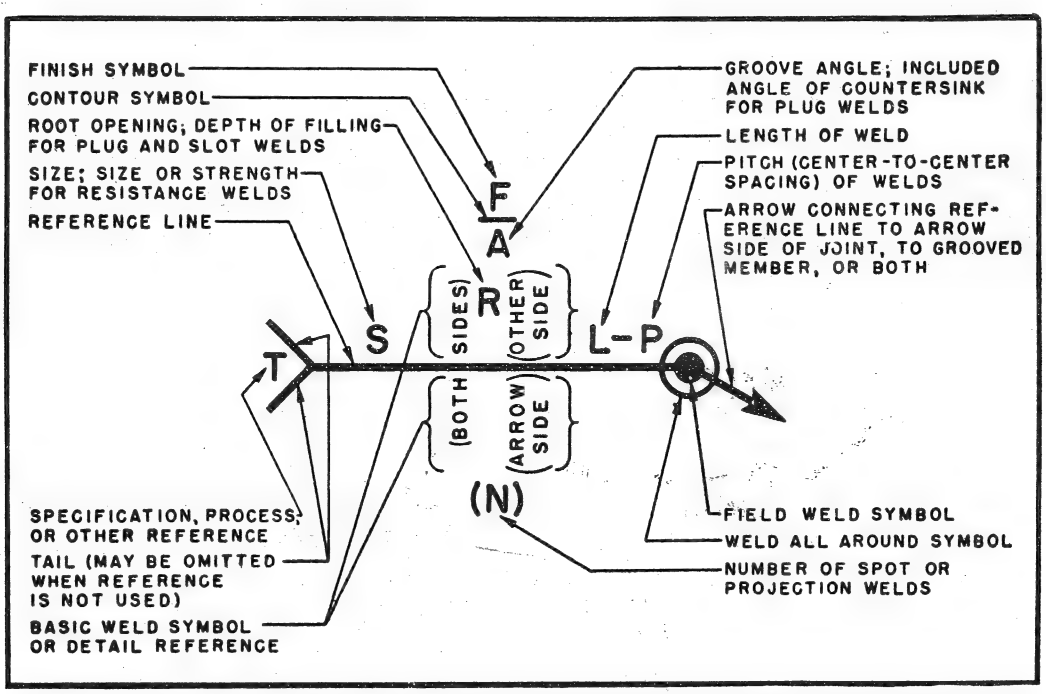


Fig. 4—Standard Location of Elements of a Welding Symbol

SECTION II—BASIC TYPES OF JOINTS AND WELDS

201. Basic Types of Joints

The basic types of joints are shown in Fig. 5 and the types of welds by which the members are frequently joined are listed thereon.

202. Basic Types of Welds

The basic types of welds indicated by the basic weld symbols are illustrated in Figs. 6 to 12 and 15 to 19, inclusive.

SECTION III—GENERAL PROVISIONS

301. Location Significance of Arrow

(*a*) In the case of groove, fillet, and flash or upset welding symbols, the arrow shall connect the welding symbol reference line to one side of the joint, and this side shall be considered the *arrow side* of the joint. The side opposite the arrow side of the joint shall be considered the *other side* of the joint. (See Figs. 6 to 12 inclusive and Fig. 19.)

(*b*) In the case of plug, slot, spot, seam and projection welding symbols, the arrow shall connect the welding symbol reference line to the outer surface of one of the members of the joint at the center line of the desired weld. The member to which the arrow points shall be considered the *arrow-side* member. The other member of the joint shall be considered the *other-side* member. (See Figs. 15 to 18, inclusive.)

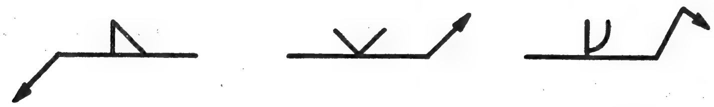
(*c*) When a joint is depicted by a single line on the drawing and the arrow of a welding symbol is directed to this line, the arrow side of the joint shall be considered as the near side of the joint in accordance with the usual conventions of drafting. (See Figs. 6 to 12, inclusive and Fig. 19.)

(*d*) When a joint is depicted as an area parallel to the plane of projection in a drawing and the arrow of a welding symbol is directed to that area, the *arrow-side* member of the joint shall be considered as the near member of the joint in accordance with the usual conventions of drafting. (See Figs. 15 to 18, inclusive.)

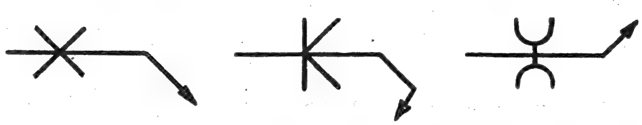
302. Location of Weld with Respect to Joint

(*a*) Welds on the arrow side of the joint shall be shown by placing the weld symbol on the side of the reference line toward the reader, thus: (See also Figs. 6*A*, 8*A*, 9*A*, 10*A*, 11*A*, 12*A*, 15*A*, 16*A* and 18*A*.)

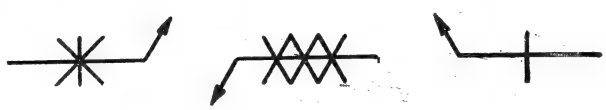
(*b*) Welds on the other side of the joint shall be shown by placing the weld symbol on the side of the reference line away from the reader, thus: (See also Figs. 6*B*, 8*B*, 9*B*, 10*B*, 11*B*, 12*B*, 15*B*, 16*B* and 18*B*.)



(*c*) Welds on both sides of the joint shall be shown by placing weld symbols on both sides of the reference line, toward and away from the reader, thus: (See also Figs. 7, 8*C*, 9*C*, 10*C*, 11*C* and 12*C*.)



(*d*) Spot, seam, flash and upset weld symbols have no arrow-side or other-side significance in themselves, although supplementary symbols used in conjunction therewith may have such significance. (See Articles 301, 906, 1007 and 1202.) Spot, seam, flash and upset weld symbols shall be centered on the reference line thus: (See also Figs. 17 and 19.)



303. Method of Drawing Symbols

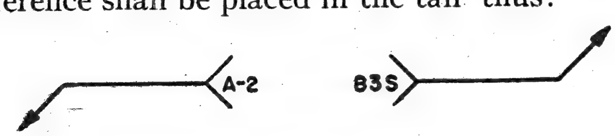
Symbols may be drawn mechanically or freehand, as desired.

304. Use of Inch, Degree and Pound Marks

Inch, degree and pound marks may be used on welding symbols or not, as desired, except that inch marks shall be used for indicating the diameter of spot and projection welds and the width of seam welds, when such welds are specified by linear dimension.

305. Location of Specification, Process or Other References

When a specification, process or other references is used with a welding symbol, the reference shall be placed in the tail thus:



306. Use of Symbols Without References

When desired, symbols may be used without specification, process or

other references in the following instances:

(*a*) When a note such as the following appears on the drawing: "Unless otherwise designated, all welds are to be made in accordance with Specification No. —."

(*b*) When the welding procedure to be used is prescribed elsewhere.

307. Use of General Notes

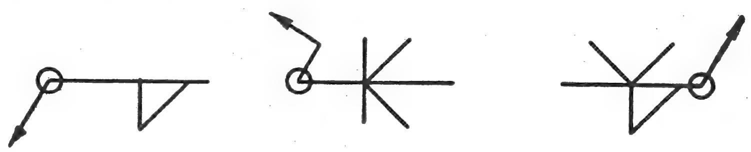
When desired, general notes such as the following may be placed on a drawing to provide detailed information pertaining to the predominating welds, and this information need not be repeated on the symbols.

"Unless otherwise indicated, all fillet welds are $^5/_{16}$ inch size."

"Unless otherwise indicated, root openings for all groove welds are $^3/_{16}$ inch.

308. Use of Weld-All-Around Symbol

Welds extending completely around a joint shall be indicated by means of the weld-all-around symbol, thus:



309. Use of Field Weld Symbol

Field welds (welds not made in a shop or at the place of initial construction) shall be indicated by means of the field weld symbol, thus:

310. Extent of Welding Denoted by Symbols

Symbols apply between abrupt changes in the direction of the welding or to the extent of hatching or dimension lines, except when the weld-all-around symbol is used. (See Figs. 23, 24, 35*A*, 36*C* and 38*A*.)

311. Weld Proportions

All welds shall be continuous and of user's standard proportions unless otherwise indicated.

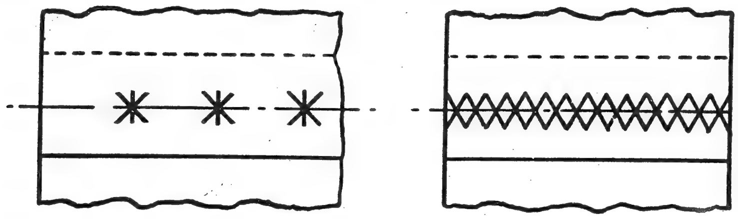
312. Finishing of Welds

Finishing of welds, other than cleaning, shall be indicated by suitable contour and finish symbols. (See Arts. 409, 505, 603, 706, 804 and 1202.)

313. Location of Weld Symbols

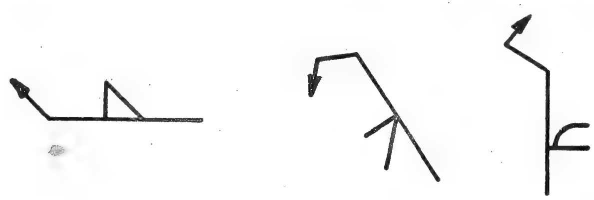
(*a*) Weld symbols, except spot and seam, shall be shown only on the welding symbol reference line and not on the lines of the drawing.

(*b*) Spot and seam weld symbols may be placed directly on drawings at the locations of the desired welds, thus· (See also Fig. 17.)



314. Construction of Fillet and Bevel- and J-Groove Welding Symbols

Fillet and bevel- and J-groove weld symbols shall be shown with the perpendicular leg *always* to the left, thus: (See also Figs. 6, 7, 9 and 11.)

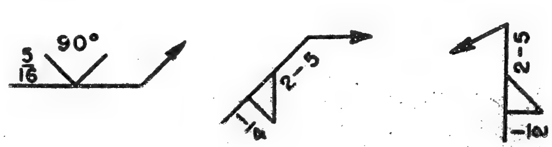


315. Use of Break in Arrow of Bevel- and J-Groove Welding Symbols

When a bevel- or J-groove weld symbol is used, the arrow shall point with a definite break toward the member which is to be chamfered, thus: (See also Figs. 9 and 11) (In cases where the member to be chamfered is obvious, the break in the arrow may be omitted.)

316. Reading of Information on Welding Symbols

Information on welding symbols shall be placed to read from left to right along the reference line in accordance with the usual conventions of drafting, thus:



317. Combined Weld Symbols

For joints having more than one weld, a symbol shall be shown for each weld, thus: (See also Figs. 20 and 27.)

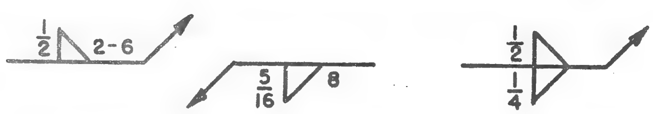
318. Designation of Special Types of Welds

When the basic weld symbols are inadequate to indicate the desired weld, the weld shall be shown by a cross section, detail or other data, with a reference thereto on the welding symbol, observing the usual location significance, thus:

SECTION IV—FILLET WELDS

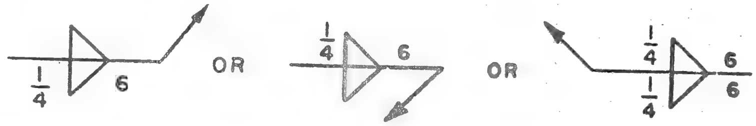
401. General

(*a*) Dimensions of fillet welds shall be shown on the same side of the reference line as the weld symbol, thus: (See also Figs. 21, 22 and 23.)

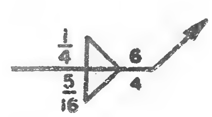


(*b*) When no general note governing the dimensions of fillet welds appears on the drawing, the dimensions of fillet welds on both sides of the joint shall be shown as follows:

(1) When both welds have the same dimensions, one or both may be dimensioned, thus:

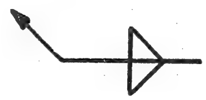


(2) When the welds differ in dimensions, both shall be dimensioned. thus:

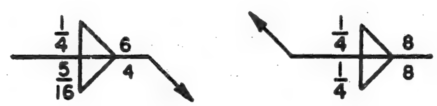


(*c*) When there appears on the drawing a general note governing the dimensions of fillet welds, such as "All fillet welds $^5/_{16}$ in. size unless otherwise noted," the dimensions of fillet welds on both sides of the joint shall be indicated as follows:

(1) When both welds have dimensions governed by the note, neither need be dimensioned, thus:

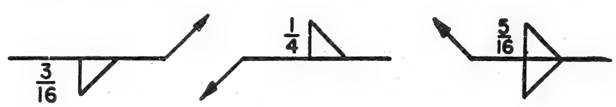


(2) When the dimensions of one or both welds differ from the dimensions given in the general note, both welds shall be dimensioned, thus:

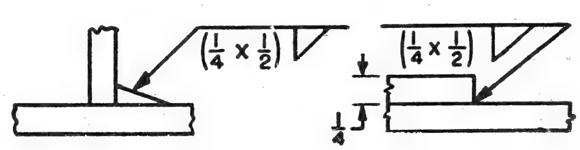


402. Size of Fillet Welds

(*a*) The size of a fillet weld shall be shown to the left of the weld symbol, thus: (See also Figs. 21*A*, 21*B*, 21*C* and 21*D*.)

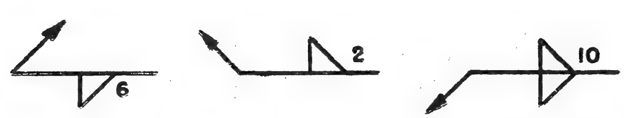


(*b*) The size of a fillet weld with unequal legs, shall be shown in parentheses to the left of the weld symbol, as shown below Weld orientation is not shown by the symbol and shall be shown on the drawing when necessary. (See also Fig. 21*D*.)



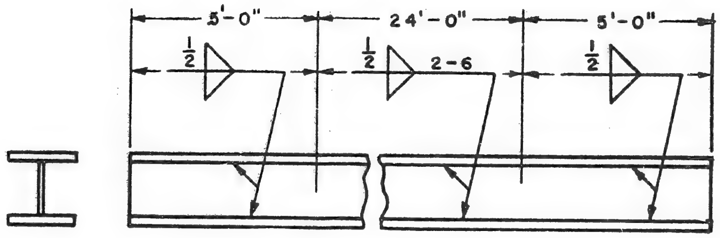
403. Length of Fillet Welds

(*a*) The length of a fillet weld, when indicated on the welding symbol, shall be shown to the right of the weld symbol, thus: (See also Fig. 21*F*.)



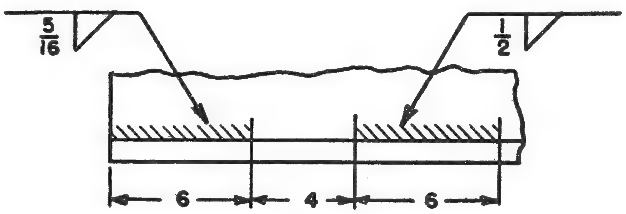
(*b*) When fillet welding extends for the full distance between abrupt changes in the direction of the welding (see Article 310), no length dimension need be shown on the welding symbol. (See Fig. 21*E*.)

(*c*) Specific lengths of fillet welding may be indicated by symbols in conjunction with dimension lines, thus: (See also Figs. 23*A* and 23*B*.)



404. Extent of Fillet Welding

(*a*) When it is desired to show the extent of fillet welding graphically, one type of hatching with definite end lines shall be used, thus:

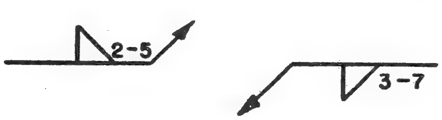


(*b*) Fillet welding extending beyond abrupt changes in the direction of the welding shall be indicated by means of additional arrows pointing to each section of the joint to be welded, as shown in Fig. 24*A*, except when the weld-all-around symbol is used.

405. Dimensioning of Intermittent Fillet Welding

(*a*) The pitch (center-to-center spacing) of intermittent fillet welding shall be shown as the distance between centers of increments on *one* side of the joint. (See Fig. 22.)

(*b*) The pitch (center-to-center spacing) of intermittent fillet welding shall be shown to the right of the length dimension, thus: (See also Fig. 22.)



(*c*) Chain intermittent fillet welding shall be shown thus: (See also Fig. 22*B*.)

(*d*) Staggered intermittent fillet welding shall be shown thus: (See also Fig. 22*C*.)

406. Termination of Intermittent Fillet Welding

(*a*) When intermittent fillet welding is used by itself, the symbol indicates that increments shall be located at the ends of the dimensioned length. (See Fig. 22.)

(*b*) When intermittent fillet welding is used between continuous fillet welding the symbol indicates that spaces equal to the pitch minus the length of one increment shall be left at the ends of the dimensioned length. (See Fig. 23*A*.)

407. Combination of Intermittent and Continuous Fillet Welding

Separate symbols shall be used for intermittent and continuous fillet welding when the two are used in combination. (See Fig. 23*A*.)

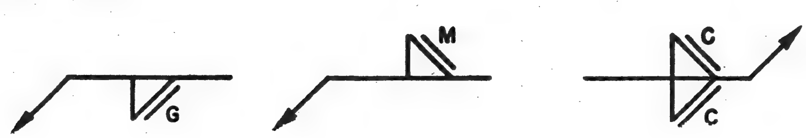
408. Fillet Welds in Holes and Slots

Fillet welds in holes and slots shall be shown by means of fillet weld symbols.

409. Surface Contour of Fillet Welds

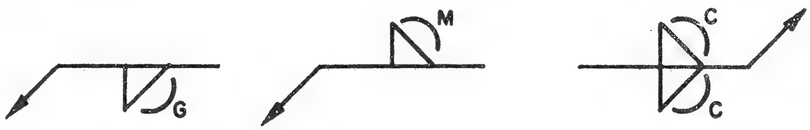
(*a*) Fillet welds that are to be welded approximately flat-faced without recourse to any method of finishing shall be shown by adding the flush-contour symbol to the weld symbol, observing the usual location significance, thus:

(*b*) Fillet welds that are to be made flat-faced by mechanical means, shall be shown by adding both the flush-contour symbol and the user's standard finish symbol* to the weld symbol, observing the usual location significance, thus:



* Finish symbols used herein indicate the method of finishing ("C" = chipping; "G" = grinding; "M" = machining) and not the degree of finish.

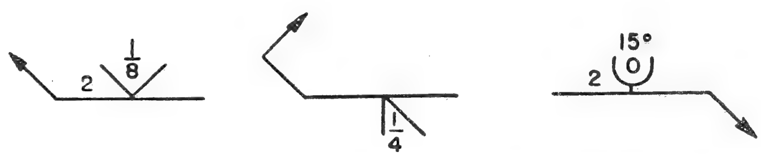
(*c*) Fillet welds that are to be mechanically finished to a convex contour, shall be shown by adding both the convex-contour symbol and the user's standard finish symbol* to the weld symbol, observing the usual location significance, thus:



SECTION V—GROOVE WELDS

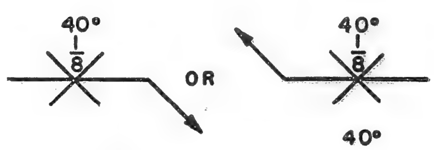
501. General

(*a*) Dimensions of groove welds shall be shown on the same side of the reference line as the weld symbol, thus: (See also Fig. 31 *B*.)

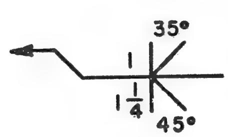


(*b*) When no general note governing the dimensions of groove welds appears on the drawing, the dimensions of double-groove welds shall be shown as follows:

(1) When both welds have the same dimensions, one or both may be dimensioned, thus:



(2) When the welds differ in dimensions, both shall be dimensioned, thus:



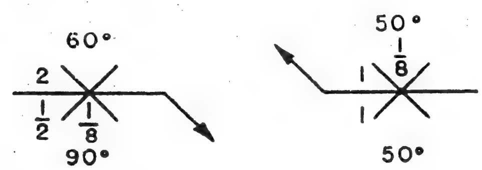
(*c*) When there appears on the drawing a general note governing the dimensions of groove welds, such as ' All V-groove welds shall have a 60° groove angle unless otherwise noted, ' the dimensions of double-groove welds shall be indicated as follows:

(1) When both welds have dimensions governed by the note, neither

* Finish symbols used herein indicate the method of finishing ("C" = chipping; "G" = grinding; M" = machining) and not the degree of finish.

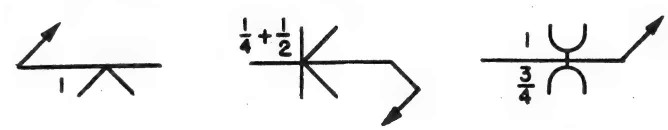
need be dimensioned, thus:

(2) When the dimensions of one or both welds differ from the dimensions given in the general note, both welds shall be dimensioned, thus:



502. Size of Groove Welds

(*a*) The size of groove welds shall be shown to the left of the weld symbol, thus: (See also Figs. 25, 26 and 27.)

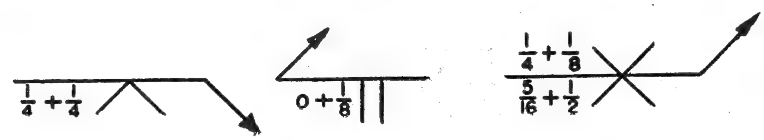


(*b*) The size of groove welds with no specified root penetration shall be shown as follows.

(1) The size of single-groove and symmetrical double-groove welds which extend completely through the member or members being joined, need not be shown on the welding symbol. (See Figs. 25*D* and 25*E*.)

(2) The size of groove welds which extend only partly through the member or members being joined, shall be shown on the welding symbol. (See Figs. 25*A*, 25*C* and 25*F*.)

(*c*) The size of groove welds with specified root penetration shall be indicated by showing both the depth of chamfering and the root penetration, separated by a plus mark and placed to the left of the weld symbol. The depth of chamfering and the root penetration shall read in that order from left to right along the reference line, thus: (See also Figs. 26 and 27.)

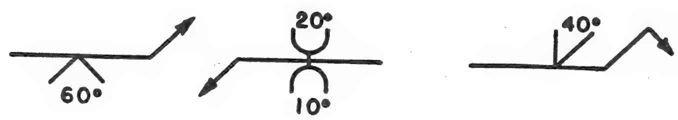


513. Groove Dimensions

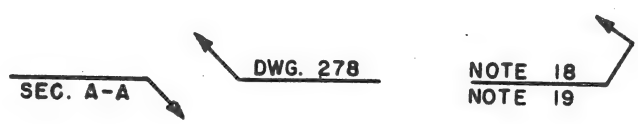
(*a*) Root opening of groove welds shall be the user's standard unless otherwise indicated. Root opening of groove welds, when not the user's

standard, shall be shown inside the weld symbol, thus: (See also Fig. 28.)

(*b*) Groove angle of groove welds shall be the user's standard, unless otherwise indicated. Groove angle of groove welds, when not the user's standard, shall be shown thus: (See also Fig. 29.)



(*c*) Groove radii and root faces of U- and J-groove welds shall be the user's standard unless otherwise indicated. When groove radii and root faces of U- and J-groove welds are not the user's standard, the weld shall be shown by a cross section, detail or other data, with a reference thereto on the welding symbol, observing the usual location significance, thus:

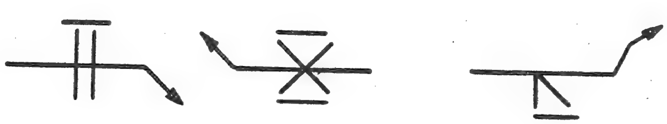


504. Designation of Back and Backing Welds

Bead-type back and backing welds of single-groove welds shall be shown by means of the bead weld symbol. (See Art. 602.)

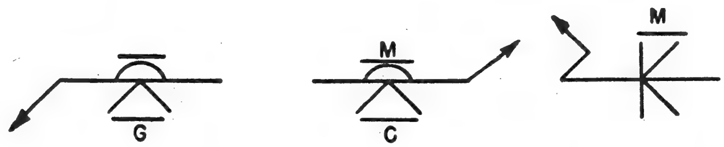
505. Surface Contour of Groove Welds

(*a*) Groove welds that are to be welded approximately flush without recourse to any method of finishing shall be shown by adding the flush-contour symbol to the weld symbol, observing the usual location significance, thus: (See also Fig. 30*A*.)

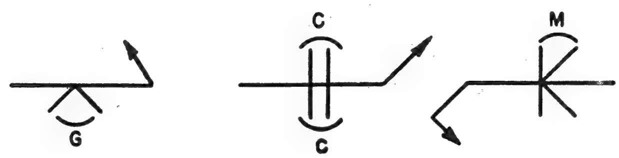


(*b*) Groove welds that are to be made flush by mechanical means shall be shown by adding both the flush-contour symbol and the user's

standard finish symbol* to the weld symbol, observing the usual location significance, thus: (See also Fig. 30*B*.)



(*c*) Groove welds that are to be mechanically finished to a convex contour shall be shown by adding both the convex-contour symbol and the user's standard finish symbol* to the weld symbol, observing the usual location significance, thus: (See also Fig. 30*C*.)



SECTION VI—BEAD WELDS

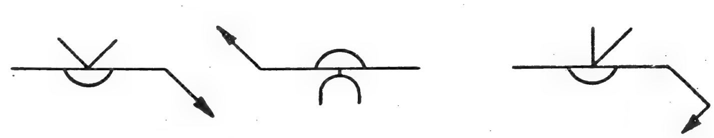
601. General

(*a*) The single bead weld symbol shall be used to indicate bead-type back or backing welds of single-groove welds. (See Fig. 13.)

(*b*) The dual bead weld symbol shall be used to indicate surfaces built up by welding. (See Fig. 14.)

602. Use of Bead Weld Symbol to Indicate Bead-Type Back or Backing Welds

(*a*) Bead welds used as back or backing welds of single-groove welds, shall be shown by placing a single bead weld symbol on the side of the reference line opposite the groove weld symbol, thus: (See also Figs. 13, 20*A* and 20*B*.)

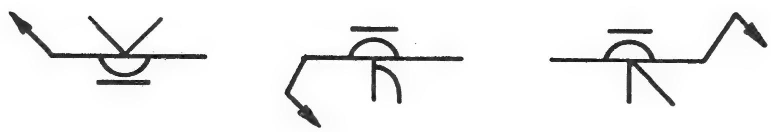


(*b*) Dimensions of bead welds used as back or backing welds shall not be shown on the welding symbol. If it is desired to specify these dimensions, they shall be shown on the drawing.

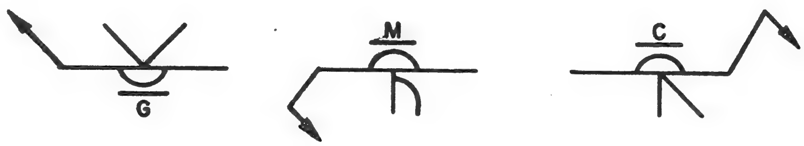
603. Surface Contour of Back or Backing Welds

(*a*) Back or backing welds that are to be welded approximately flush without recourse to any method of finishing shall be shown by adding the flush-contour symbol to the bead weld symbol, thus:

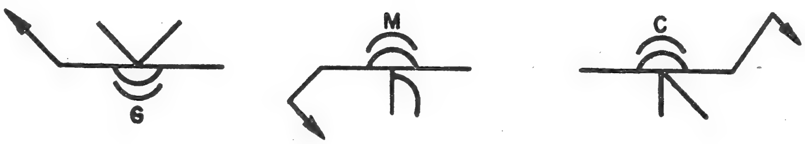
* Finish symbols used herein indicate the method of finishing ("*C*" = chipping; "*G*" = grinding; "*M*" = machining) and not the degree of finish.



(*b*) Back or backing welds that are to be made flush by mechanical means shall be shown by adding both the flush-contour symbol and the user's standard finish symbol* to the bead weld symbol, thus:



(*c*) Back or backing welds that are to be mechanically finished to a convex contour shall be shown by adding both the convex contour symbol and the user's standard finish symbol* to the bead weld symbol, thus:



604. Use of Bead Weld Symbol to Indicate Surfaces Built Up by Welding

(*a*) Surfaces built up by welding, whether by single- or multiple-pass bead welds, shall be shown by the dual bead weld symbol, thus: (See also Fig. 14.)

(*b*) The dual bead weld symbol does not indicate the welding of a joint, and hence has no arrow- or other-side significance. This symbol shall be drawn on the side of the reference line toward the reader and the arrow shall point clearly to the surface on which the weld is to be deposited. (See Fig 14.)

(*c*) Dimensions used in conjunction with the dual bead weld symbol shall be shown on the same side of the reference line as the weld symbol, thus: (See also Fig. 14.)

* Finish symbols used herein indicate the method of finishing ("C" = chipping; "G" = grinding, "M" = machining) and not the degree of finish.

605. Size (Height) of Surfaces Built Up by Welding

(*a*) The size of a surface built up by welding shall be indicated by showing the minimum height of the weld deposit to the left of the weld symbol, thus: (See also Fig. 14*A*.)

(*b*) When no specific height of weld deposit is desired, no size dimension need be shown on the welding symbol.

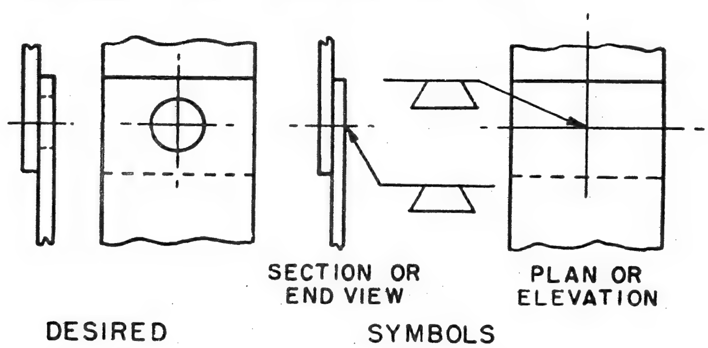
606. Extent, Location and Orientation of Surfaces Built Up by Welding

(*a*) When the entire area of a plane or curved surface is to be built up by welding, no dimension other than size (height of deposit) need be shown on the welding symbol. (See Fig. 14*C*.)
(*b*) When a portion of the area of a plane or curved surface is to be built up by welding, the extent, location and orientation of the area to be built up shall be indicated on the drawing. (See Fig. 14*D*.)

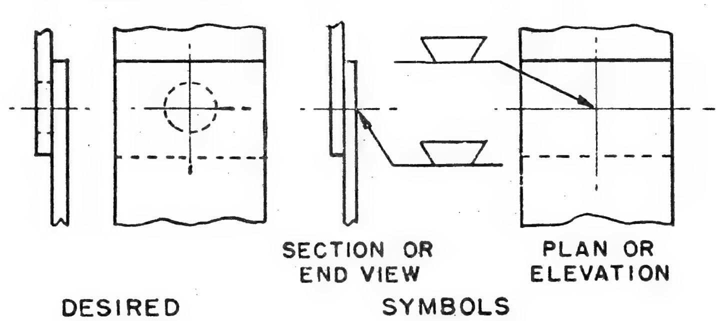
SECTION VII—PLUG WELDS

701. General

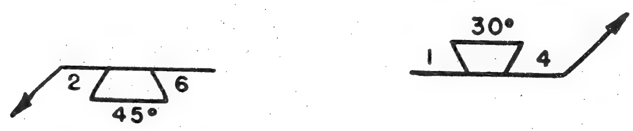
(*a*) Holes in the arrow-side member of a joint for plug welding shall be indicated by placing the weld symbol on the side of the reference line toward the reader, thus: (See also Fig. 15A.)



(*b*) Holes in the other-side member of a joint for plug welding shall be indicated by placing the weld symbol on the side of the reference line away from the reader, thus: (See also Fig. 15B.)



(*c*) Dimensions of plug welds shall be shown on the same side of the reference line as the weld symbol, thus: (See also Fig. 32.)



(*d*) The plug weld symbol shall not be used to designate fillet welds in holes. (See Article 408.)

702. Size of Plug Welds

The size of a plug weld shall be shown to the left of the weld symbol, thus: (See also Fig. 32*A*.)

703. Angle of Countersink

(*a*) Included angle of countersink of plug welds shall be the user's standard unless otherwise indicated. Included angle of countersink, when not the user's standard, shall be shown thus: (See also Fig. 32*B*.)

704. Depth of Filling

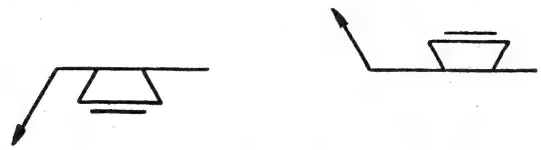
(*a*) Depth of filling of plug welds shall be complete unless otherwise indicated. When the depth of filling is less than complete, the depth of filling, in inches, shall be shown inside the weld symbol, thus: (See also Fig. 32*C*.)

705. Spacing of Plug Welds

Pitch (center-to-center spacing) of plug welds shall be shown to the right of the weld symbol, thus: (See also Fig. 32*D*.)

706. Surface Contour of Plug Welds

(*a*) Plug welds that are to be welded approximately flush without recourse to any method of finishing shall be shown by adding the flush-contour symbol to the weld symbol, thus:

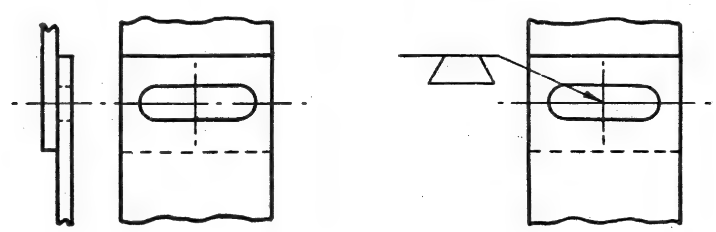


(*b*) Plug welds that are to be made flush by mechanical means shall be shown by adding both the flush-contour symbol and the user's standard finish symbol* to the weld symbol, thus:

SECTION VIII—SLOT WELDS

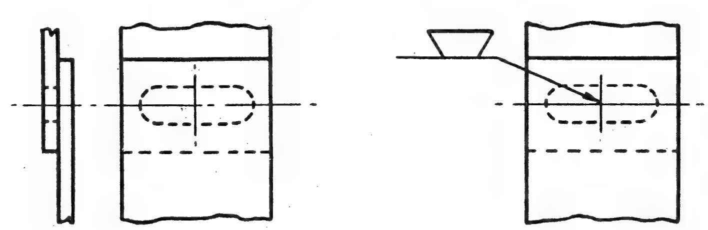
801. General

(*a*) Slots in the arrow-side member of a joint for slot welding shall be indicated by placing the weld symbol on the side of the reference line toward the reader, thus: (See also Fig. 16*A*.)



DESIRED SYMBOL

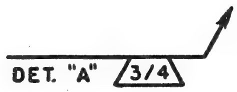
(*b*) Slots in the other-side member of a joint for slot welding shall be indicated by placing the weld symbol on the side of the reference line away from the reader, thus: (See also Fig. 16*B*.)

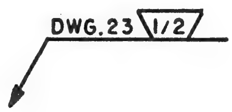


DESIRED SYMBOL

* Finish symbols used herein indicate the method of finishing ("C" = chipping; "G" = grinding; "M" = machining) and not the degree of finish.

(*c*) Dimensions of slot welds shall be shown on the same side of the reference line as the weld symbol, thus: (See also Fig 33.)

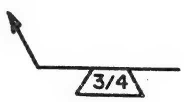


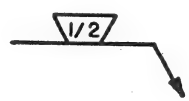


(*d*) The slot weld symbol shall not be used to designate fillet welds in slots. (See Article 408.)

802. Depth of Filling

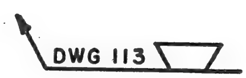
(*a*) Depth of filling of slot welds shall be complete unless otherwise indicated. When the depth of filling is less than complete, the depth of filling, in inches, shall be shown inside the weld symbol, thus: (See also Fig. 33*B*.)





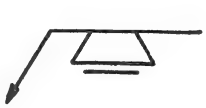
803. Details of Slot Welds

Length, width, spacing, included angle of countersink, orientation and location of slot welds cannot be shown on the welding symbol. These data shall be shown on the drawing or by a detail with a reference thereto on the welding symbol, observing the usual location significance thus: (See also Fig. 33.)



804. Surface Contour of Slot Welds

(*a*) Slot welds that are to be welded approximately flush without recourse to any method of finishing shall be shown by adding the flush-contour symbol to the weld symbol, thus:



(*b*) Slot welds that are to be made flush by mechanical means shall be shown by adding both the flush-contour symbol and the user's standard finish symbol* to the weld symbol, thus:

* Finish symbols used herein indicate the method of finishing ("*C*" = chipping; "*G*" = grinding; "*M*" = machining) and not the degree of finish.

SECTION IX—SPOT WELDS

901. General

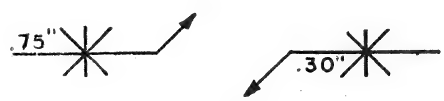
(*a*) Spot weld symbols have no arrow- or other-side significance in themselves, although supplementary symbols used in conjunction therewith may have such significance (See Article 906.) Spot weld symbols shall be centered on the reference line. (See Fig. 17A.)

(*b*) Dimensions of spot welds may be shown on either side of the reference line.

902. Size of Spot Welds

Spot welds shall be dimensioned by either size or strength, as follows:

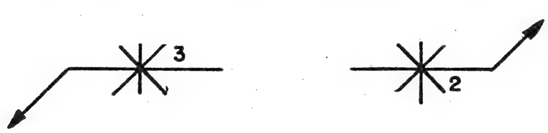
(1) The size of spot welds shall be designated as the diameter of the weld expressed decimally in hundredths of an inch, and shall be shown, with inch marks, to the left of the weld symbol, thus: (See also Fig. 34*A*.)



(2) The strength of spot welds shall be designated as the minimum acceptable shear strength in pounds per spot, and shall be shown to the left of the weld symbol, thus: (See also Fig. 34*B*.)

903. Spacing of Spot Welds

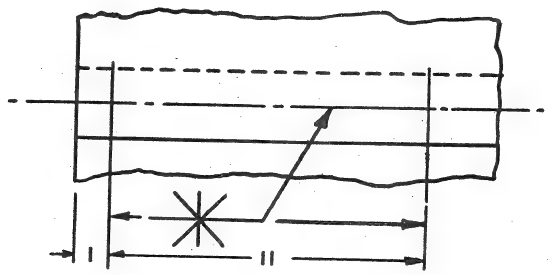
(*a*) The pitch (center-to-center spacing) of spot welds shall be shown to the right of the weld symbol, thus: (See also Fig. 34*C*.)



(*b*) When spot weld symbols are shown directly on the drawing, spacing shall be shown by dimensions. (See Fig. 34*D*.)

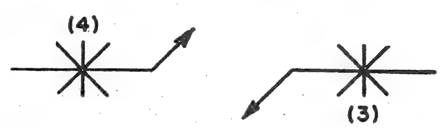
904. Extent of Spot Welding

When spot welding extends less than the distance between abrupt changes in the direction of the welding, or less than the full length of the joint (see Article 310), the extent shall be dimensioned, thus: (See also Fig. 35*A*)



905. Number of Spot Welds

When a definite number of spot welds is desired in a certain joint, the number shall be shown in parentheses either above or below the weld symbol, thus: (See also Fig. 35*B*.)



906. Flush Spot-Welded Joints

When the exposed surface of one member of a spot-welded joint is to be flush, that surface shall be indicated by adding the flush-contour symbol to the weld symbol, observing the usual location significance, thus:

SECTION X—SEAM WELDS

1001. General

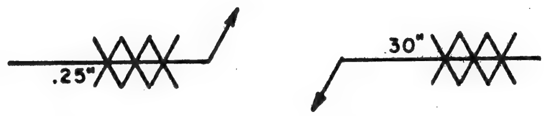
(*a*) Seam weld symbols have no arrow- or other-side significance in themselves, although supplementary symbols used in conjunction therewith may have such significance. (See Article 1007.) Seam weld symbols shall be centered on the reference line (See Fig. 17 B)

(*b*) Dimensions of seam welds may be shown on either side of the reference line

1002. Size of Seam Welds

Seam welds shall be dimensioned by either size or strength as follows:

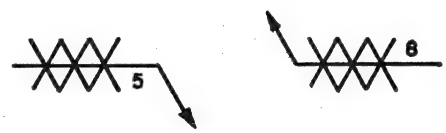
(1) The size of seam welds shall be designated as the width of the weld expressed decimally in hundredths of an inch, and shall be shown, with inch marks, to the left of the weld symbol, thus: (See also Fig. 36*A*.)



(2) The strength of seam welds shall be designated as the minimum acceptable shear strength in pounds per linear inch, and shall be shown to the left of the weld symbol, thus: (See also Fig. 36*B*.)

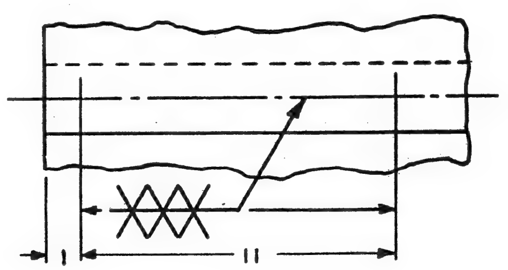
1003. Length of Seam Welds

(*a*) The length of a seam weld, when indicated on the welding symbol, shall be shown to the right of the weld symbol, thus: (See also Fig. 36*A*.)



(*b*) When seam welding extends for the full distance between abrupt changes in the direction of the welding (see Article 310), no length dimension need be shown on the welding symbol.

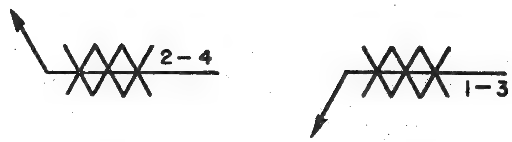
(*c*) When seam welding extends less than the distance between abrupt changes in the direction of the welding, or less than the full length of the joint (see Article 310), the extent shall be dimensioned, thus: (See also Fig. 36*C*.)



1004. Dimensioning of Intermittent Seam Welding

(*a*) The pitch (center-to-center spacing) of intermittent seam welding shall be shown as the distance between centers of the weld increments.

(*b*) The pitch (center-to-center spacing) of intermittent seam welding shall be shown to the right of the length dimension, thus: (See also Fig. 36*A*.)



1005. Termination of Intermittent Seam Welding

(*a*) When intermittent seam welding is used by itself, the symbol indicates that increments shall be located at the ends of the dimensioned length. (See Fig. 36*A*.)

(*b*) When intermittent seam welding is used between continuous seam welding, the symbol indicates that spaces equal to the pitch minus the length of one increment shall be left at the ends of the dimensioned length.

1006. Combination of Intermittent and Continuous Seam Welding

Separate symbols shall be used for intermittent and continuous seam welding when the two are used in combination.

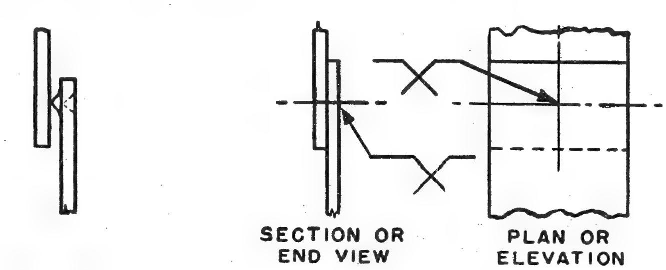
1007. Flush Seam-Welded Joints

When the exposed surface of one member of a seam-welded joint is to be flush, that surface shall be indicated by adding the flush-contour symbol to the weld symbol, observing the usual location significance, thus:

SECTION XI—PROJECTION WELDS

1101. General

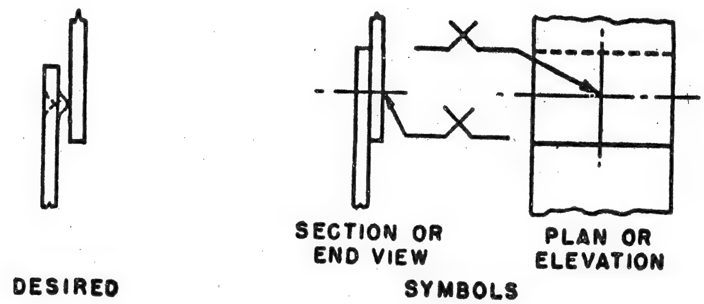
(*a*) Embossments on the arrow-side member of a joint for projection welding shall be indicated by placing the weld symbol on the side of the reference line toward the reader, thus: (See also Fig. 18*A*.)



SECTION OR END VIEW   PLAN OR ELEVATION

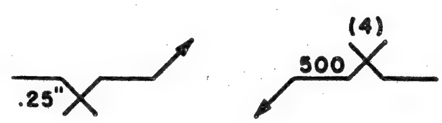
DESIRED   SYMBOLS

(*b*) Embossments on the other-side member of a joint for projection welding shall be indicated by placing the weld symbol on the side of the reference line away from the reader, thus: (See also Fig. 18*B*.)



(*c*) Proportions of projections shall be shown by a detail or other suitable means.

(*d*) Dimensions of projection welds shall be shown on the same side of the reference line as the weld symbol, thus: (See also Fig. 38*C*.)



1102. Size of Projection Welds

Projection welds shall be dimensioned by either size or strength, as follows:

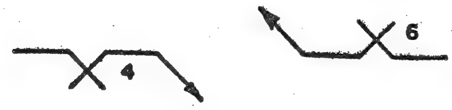
(1) The size of projection welds shall be designated as the diameter of the weld expressed decimally in hundredths of an inch, and shall be shown, with inch marks, to the left of the weld symbol, thus: (See also Fig. 37*A*.)

(2) The strength of projection welds shall be designated as the minimum acceptable shear strength in pounds per weld, and shall be shown to the left of the weld symbol, thus: (See also Fig. 37*B*.)

1103. Spacing of Projection Welds

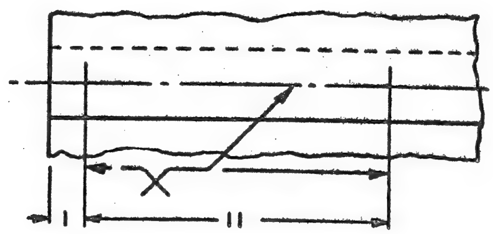
The pitch (center-to-center spacing) of projection welds shall be shown

to the right of the weld symbol, thus. (See also Fig. 37*C*.)



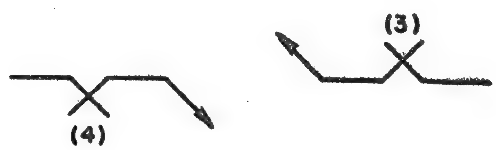
1104. Extent of Projection Welding

When projection welding extends less than the distance between abrupt changes in the direction of the welding, or less than the full length of the joint (see Article 310), the extent shall be dimensioned, thus: (See also Fig. 38*A*.)



1105. Number of Projection Welds

When a definite number of projection welds is desired in a certain joint, the number shall be shown in parentheses, thus: (See also Fig. 38*B*.)



1106. Flush Projection-Welded Joints

When the exposed surface of one member of a projection welded joint is to be made flush, that surface shall be indicated by adding the flush-contour symbol to the weld symbol, observing the usual location significance, thus:

SECTION XII—FLASH AND UPSET WELDS

1201. General

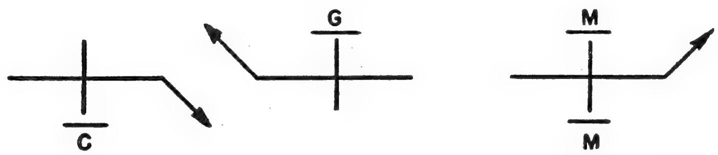
(*a*) Flash and upset weld symbols have no arrow-side or other-side

significance in themselves although supplementary symbols used in conjunction therewith may have such significance (see Article 1202). Flash or upset weld symbols shall be centered in the reference line. (See Fig. 19.)

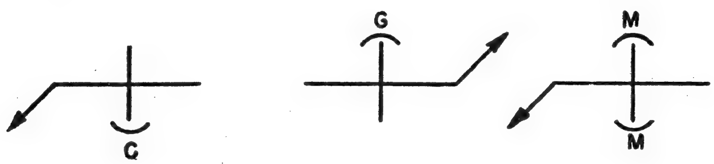
(*b*) Dimensions of flash and upset welds shall not be shown on the welding symbol.

1202. Surface Contour of Flash and Upset Welds

(*a*) Flash and upset welds that are to be made flush by mechanical means shall be shown by adding both the flush-contour symbol and the user's standard finish symbol* to the weld symbol, observing the usual location significance, thus: (See also Fig. 39*A*.)



(*b*) Flash and upset welds that are to be mechanically finished to a convex contour shall be shown by adding both the convex-contour symbol and the user's standard finish symbol* to the weld symbol, observing the usual location significance, thus: (See also Fig. 39*B*.)



* Finish symbols used herein indicate the method of finishing ("*C*" = chipping; "*G*" = grinding; "*M*" = machining) and not the degree of finish.

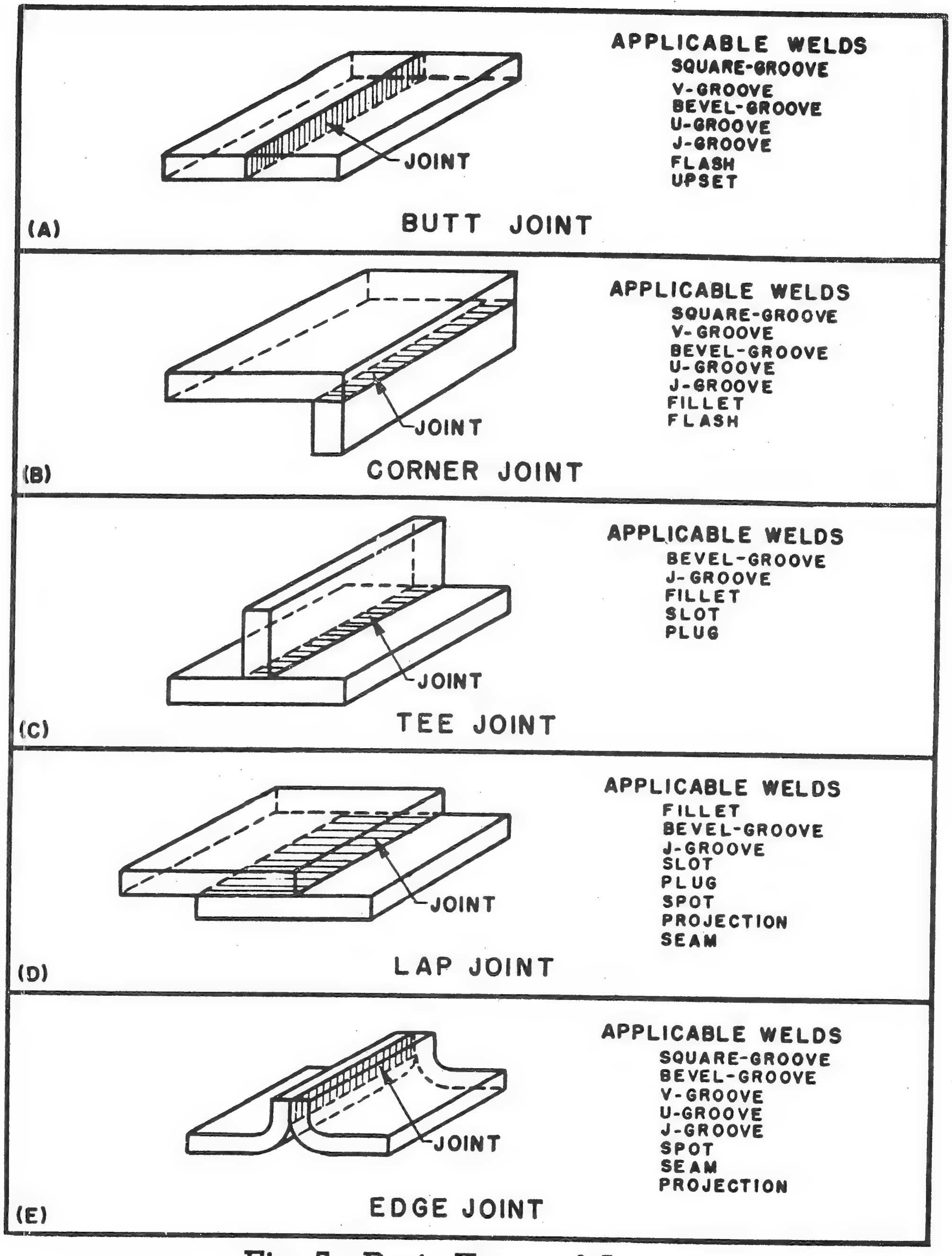


Fig. 5—Basic Types of Joints

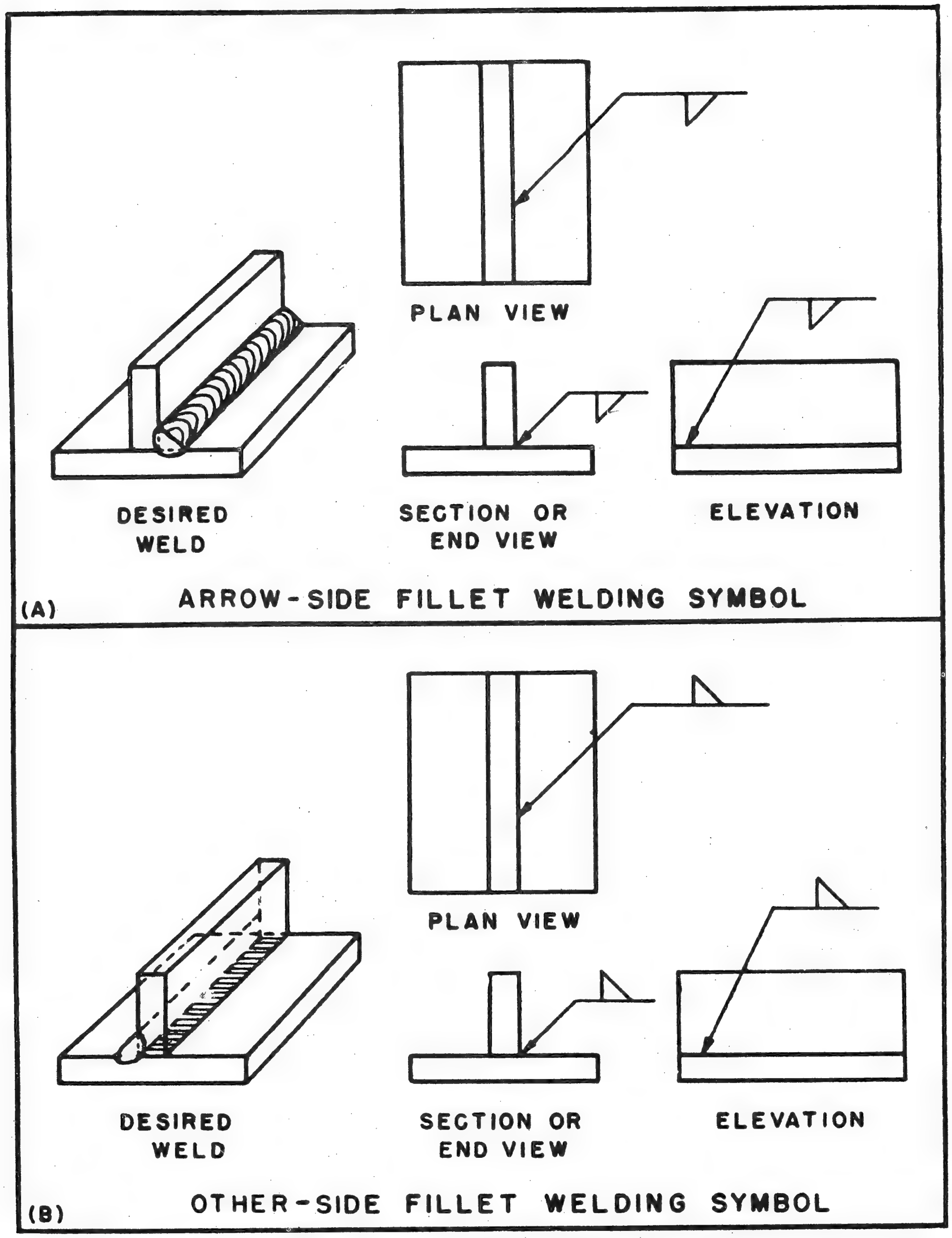


Fig. 6—Application of Fillet Welding Symbols

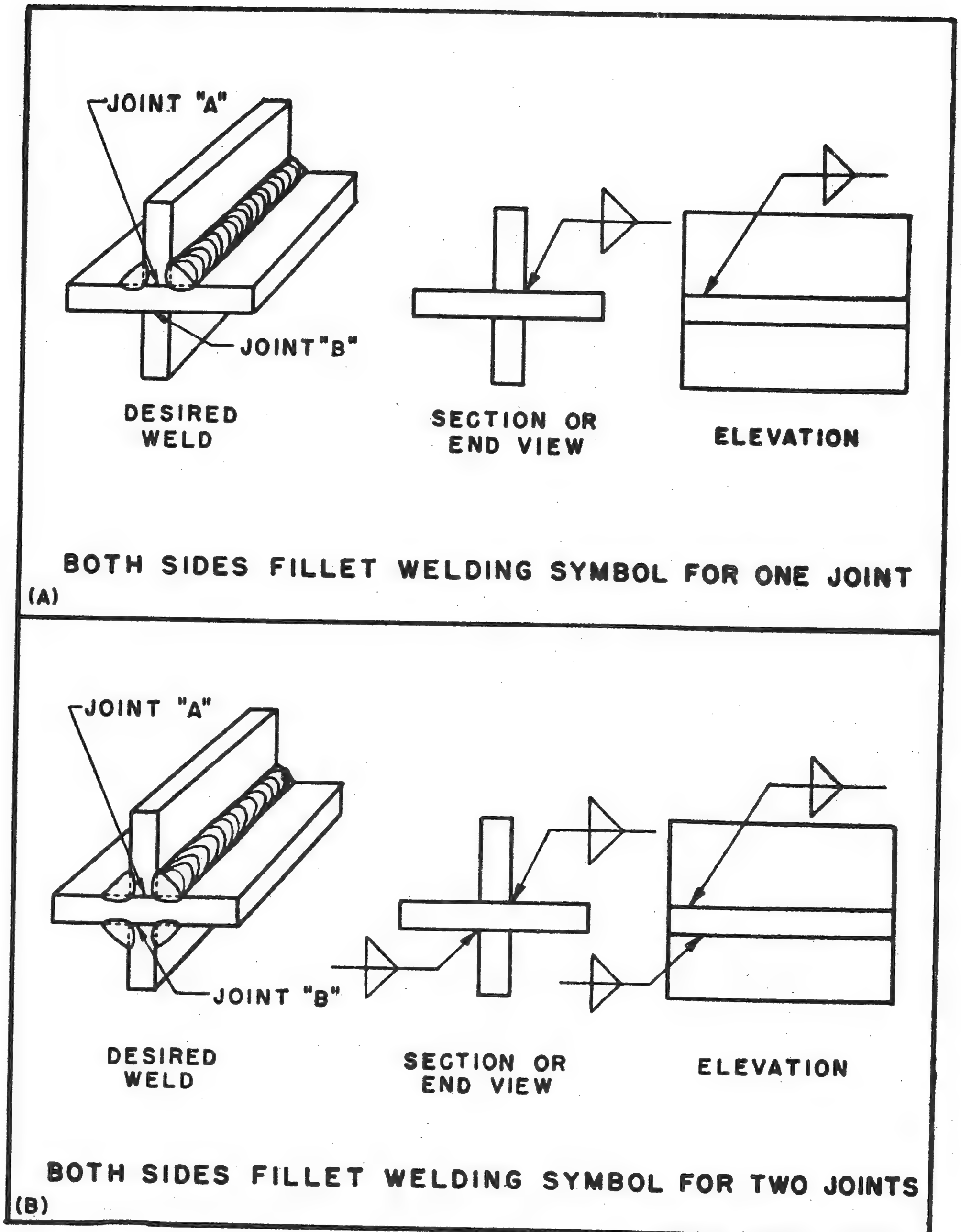


Fig. 7—Application of Fillet Welding Symbols

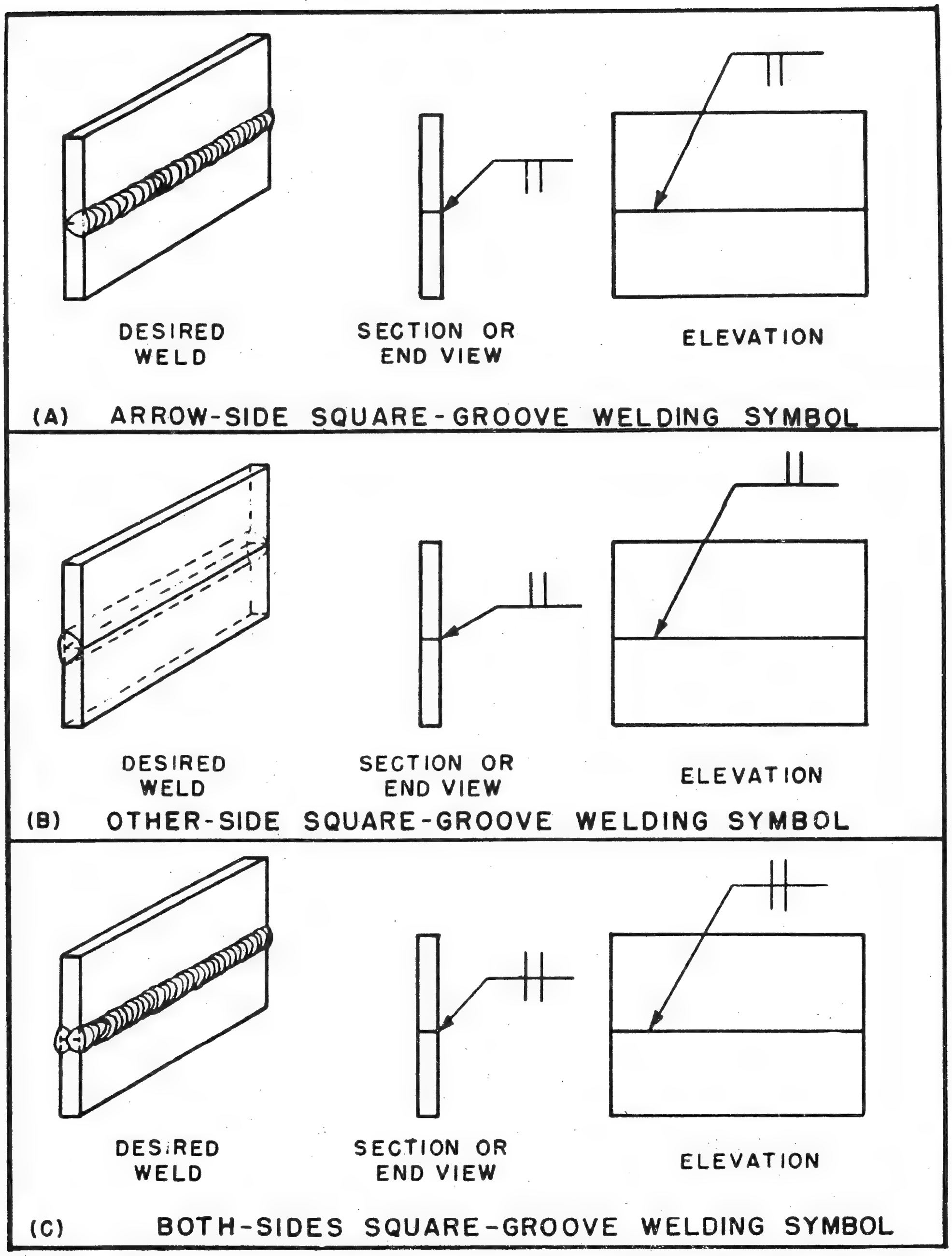


Fig 8—Application of Square-Groove Welding Symbols

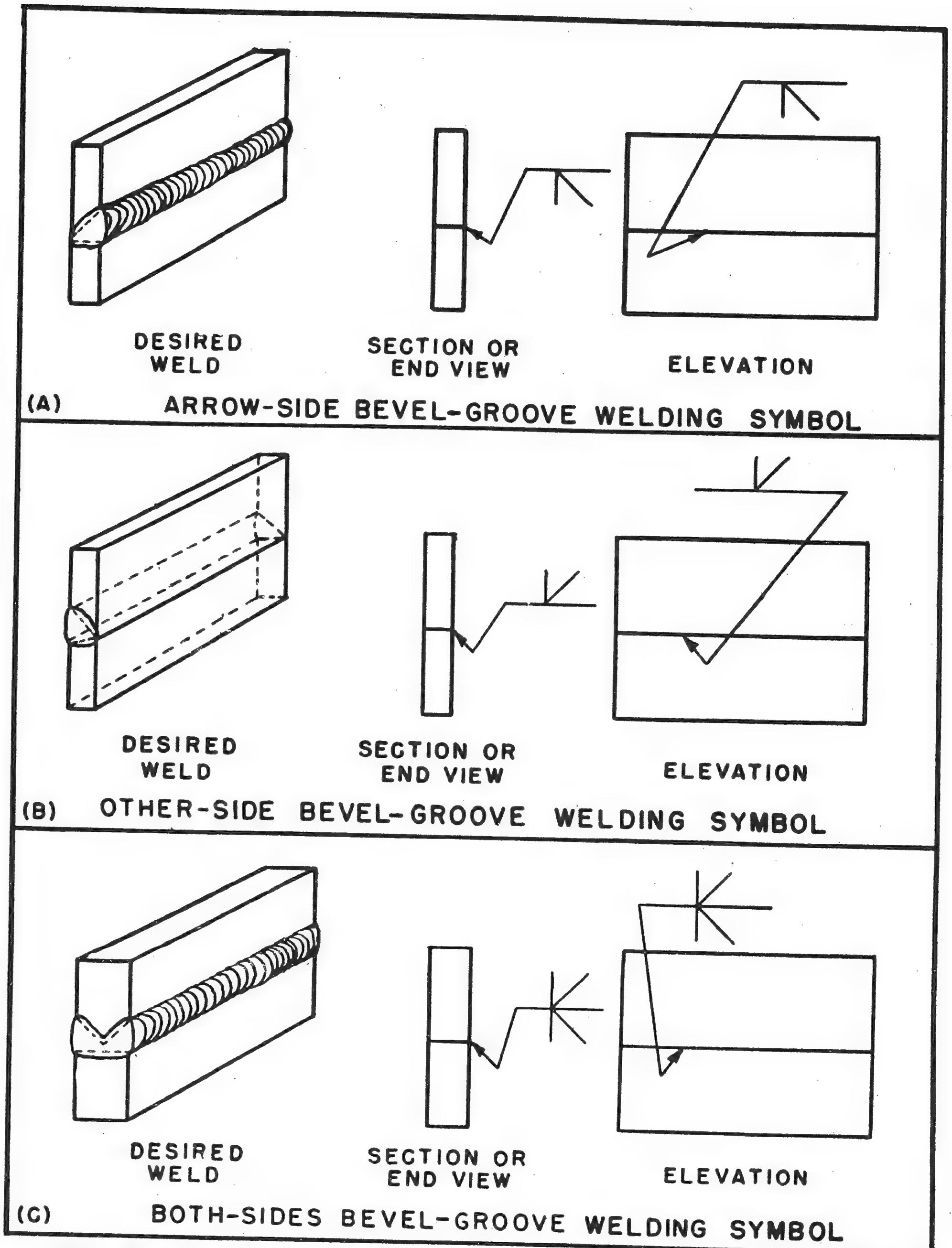


Fig. 9—Application of Bevel-Groove Welding Symbols

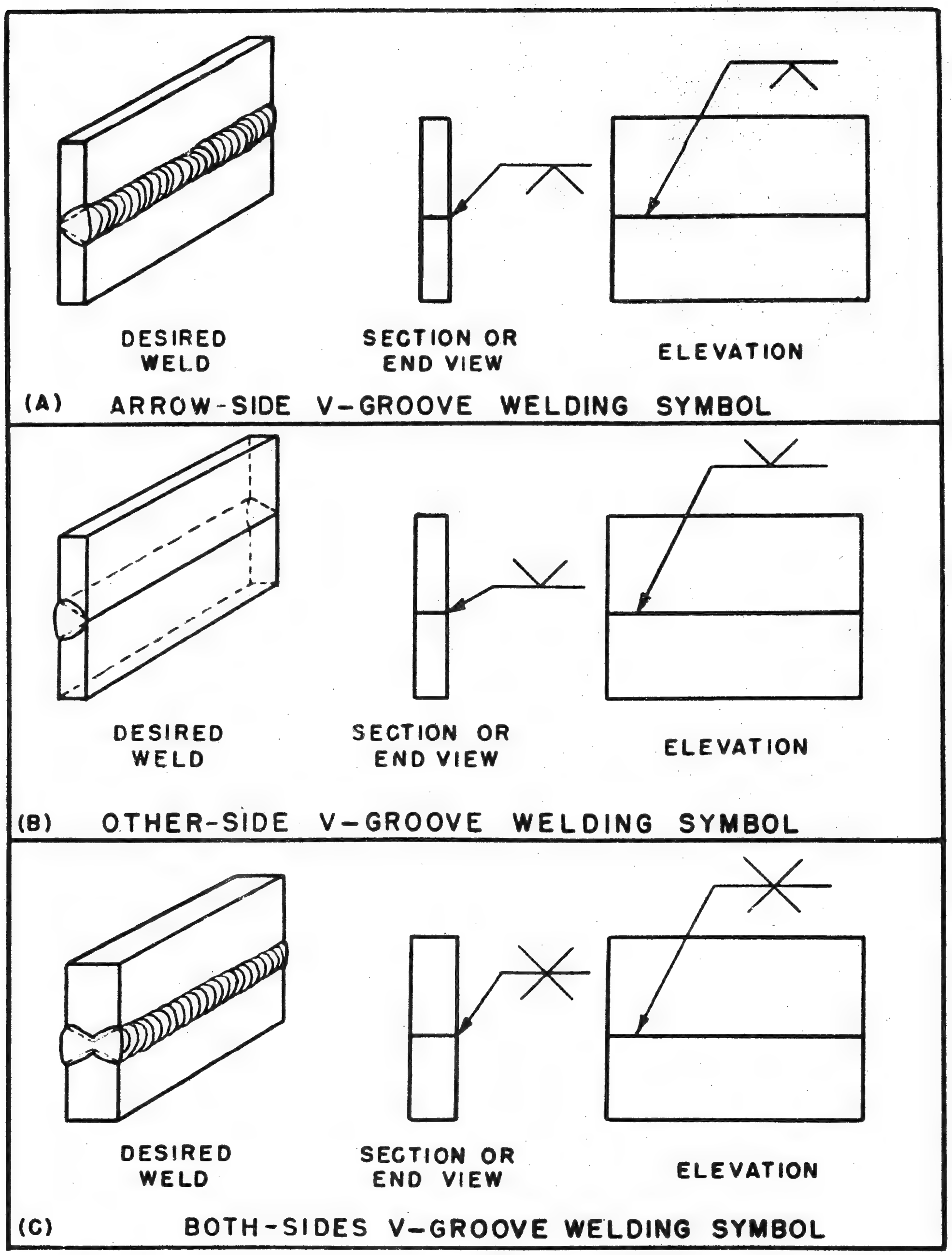


Fig. 10—Application of V-Groove Welding Symbols

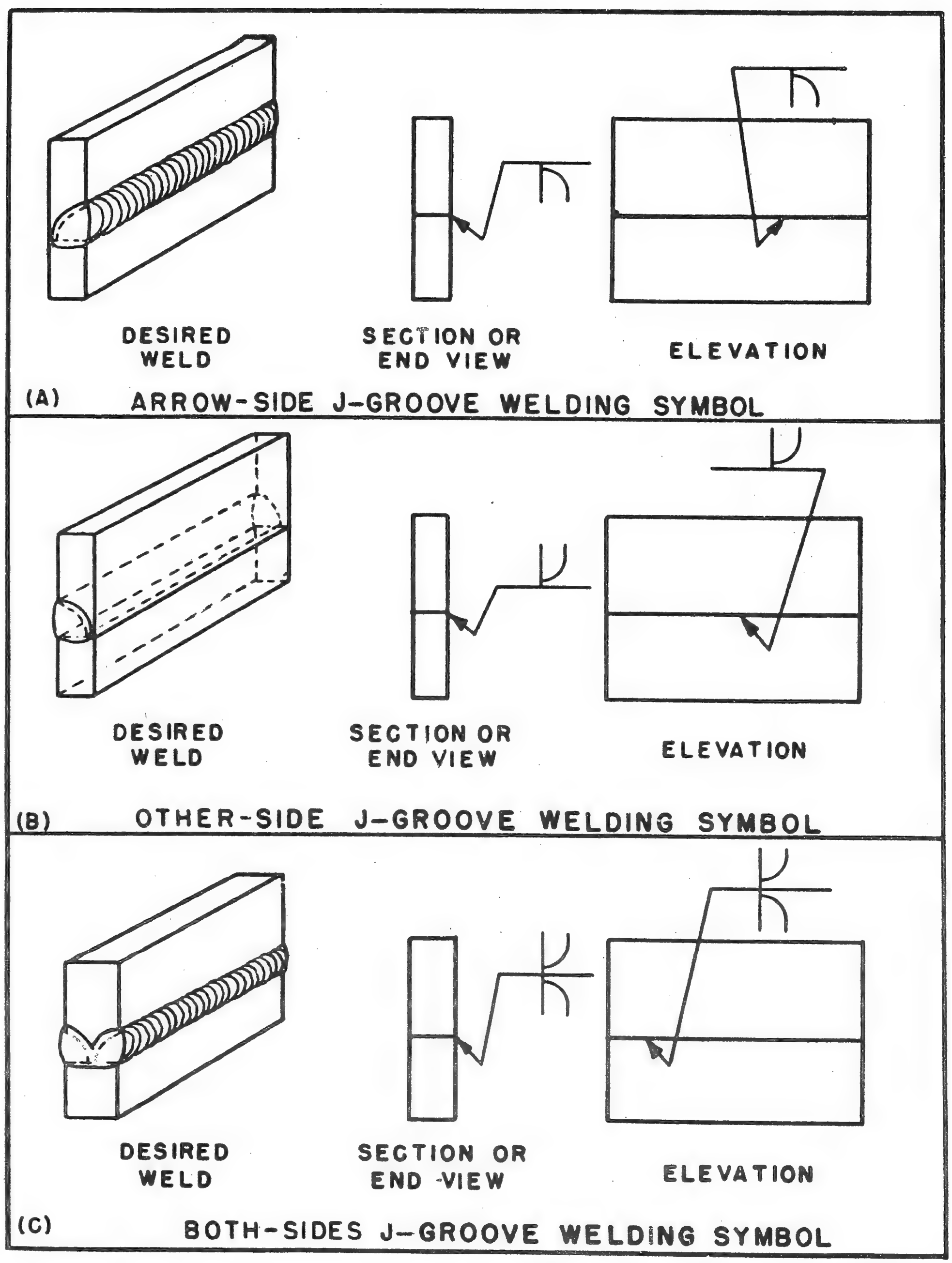


Fig. 11—Application of J-Groove Welding Symbols

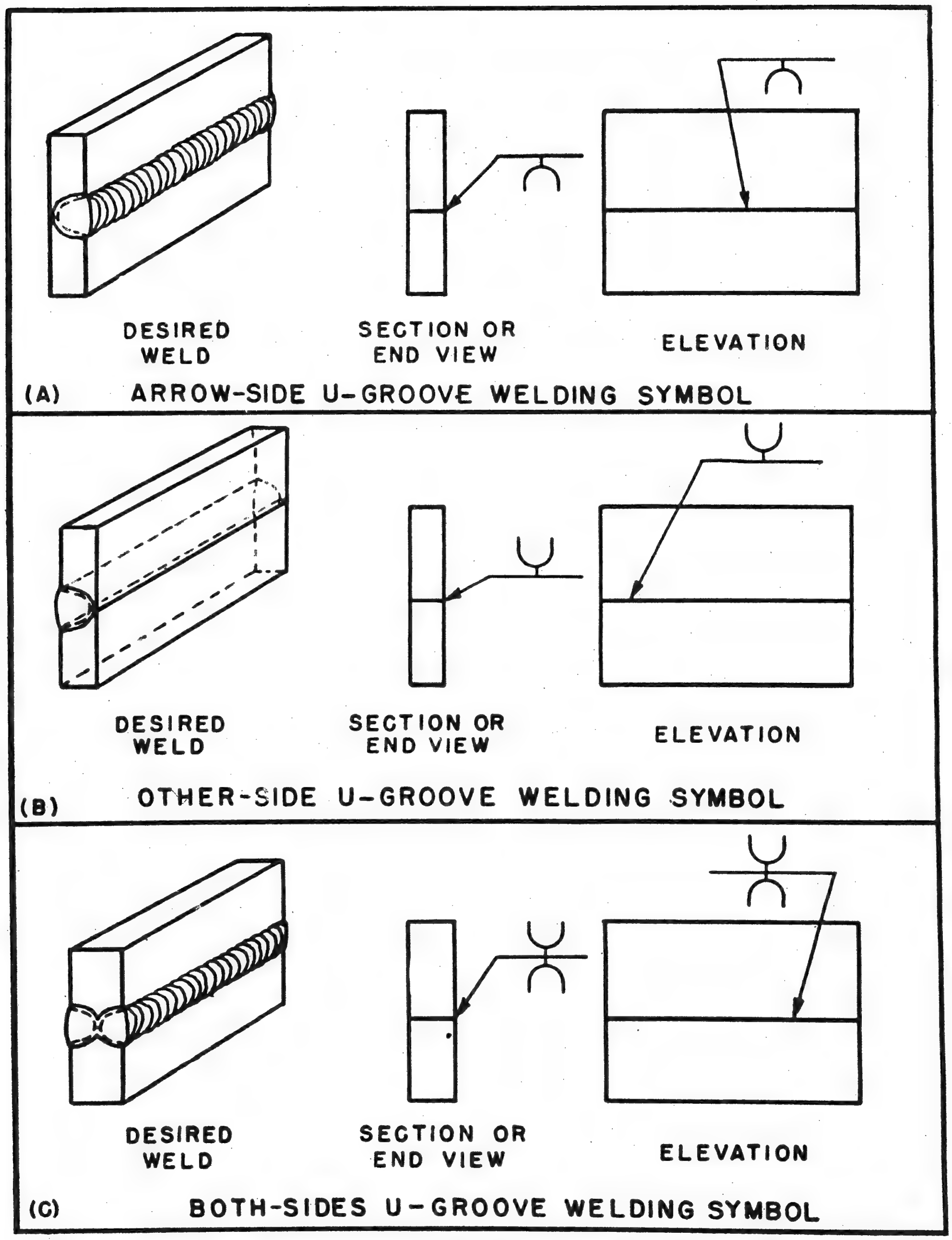


Fig. 12—Application of U-Groove Welding Symbols

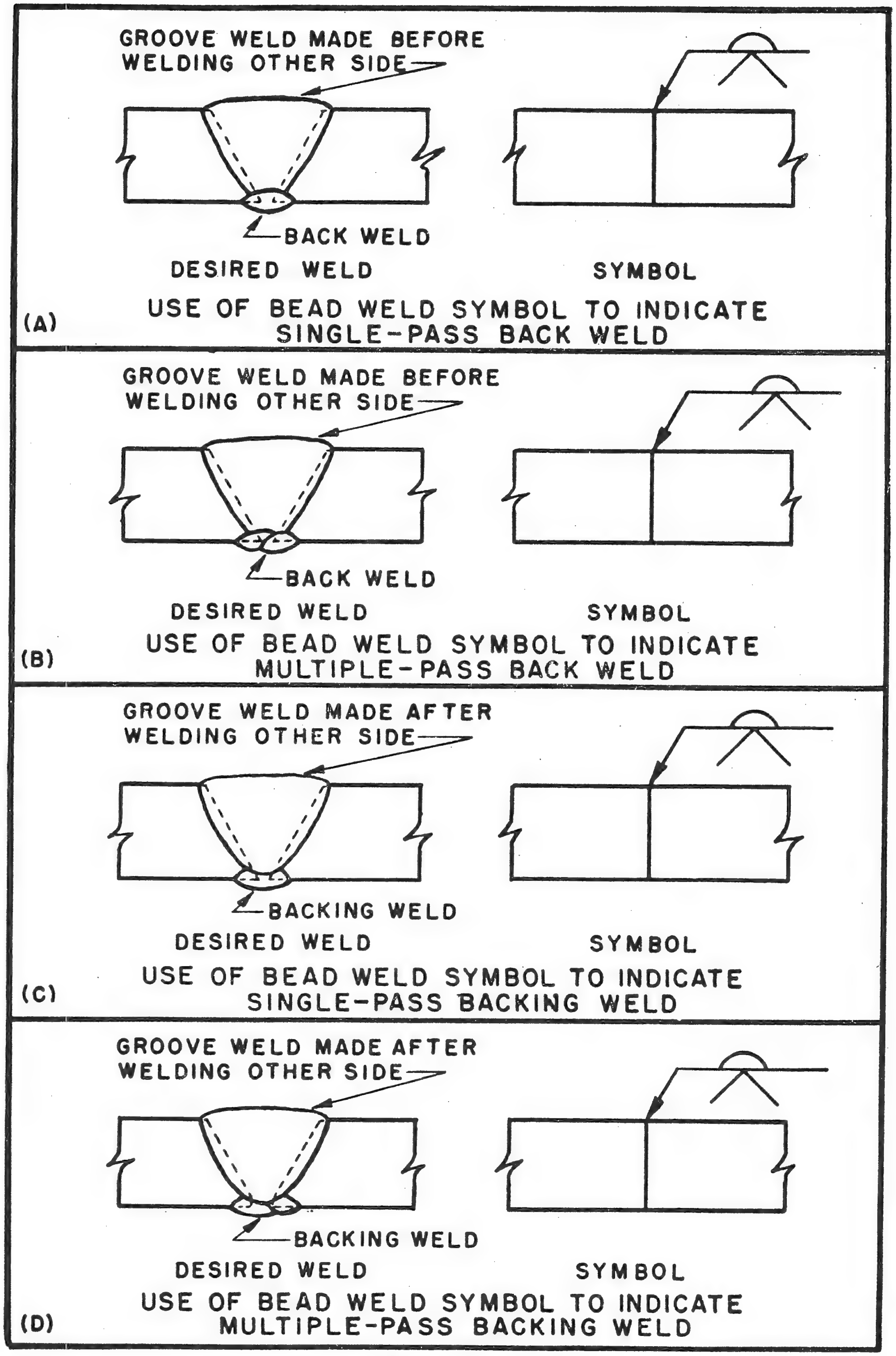


Fig. 13—Application of Bead Weld Symbol to Indicate Bead-Type Back and Backing Welds

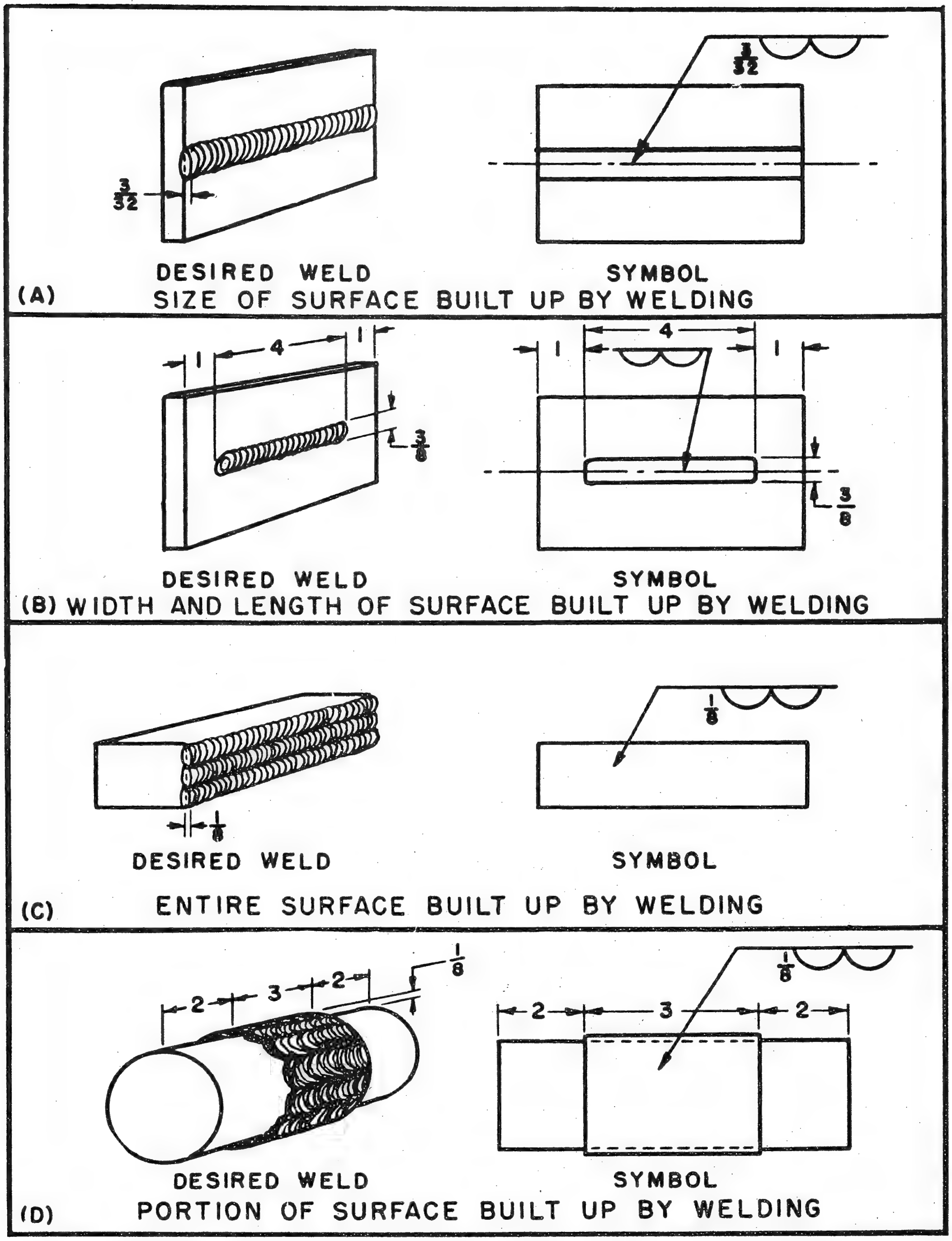


Fig. 14—Application of Dual Bead Weld Symbol to Indicate Surfaces Built Up by Welding

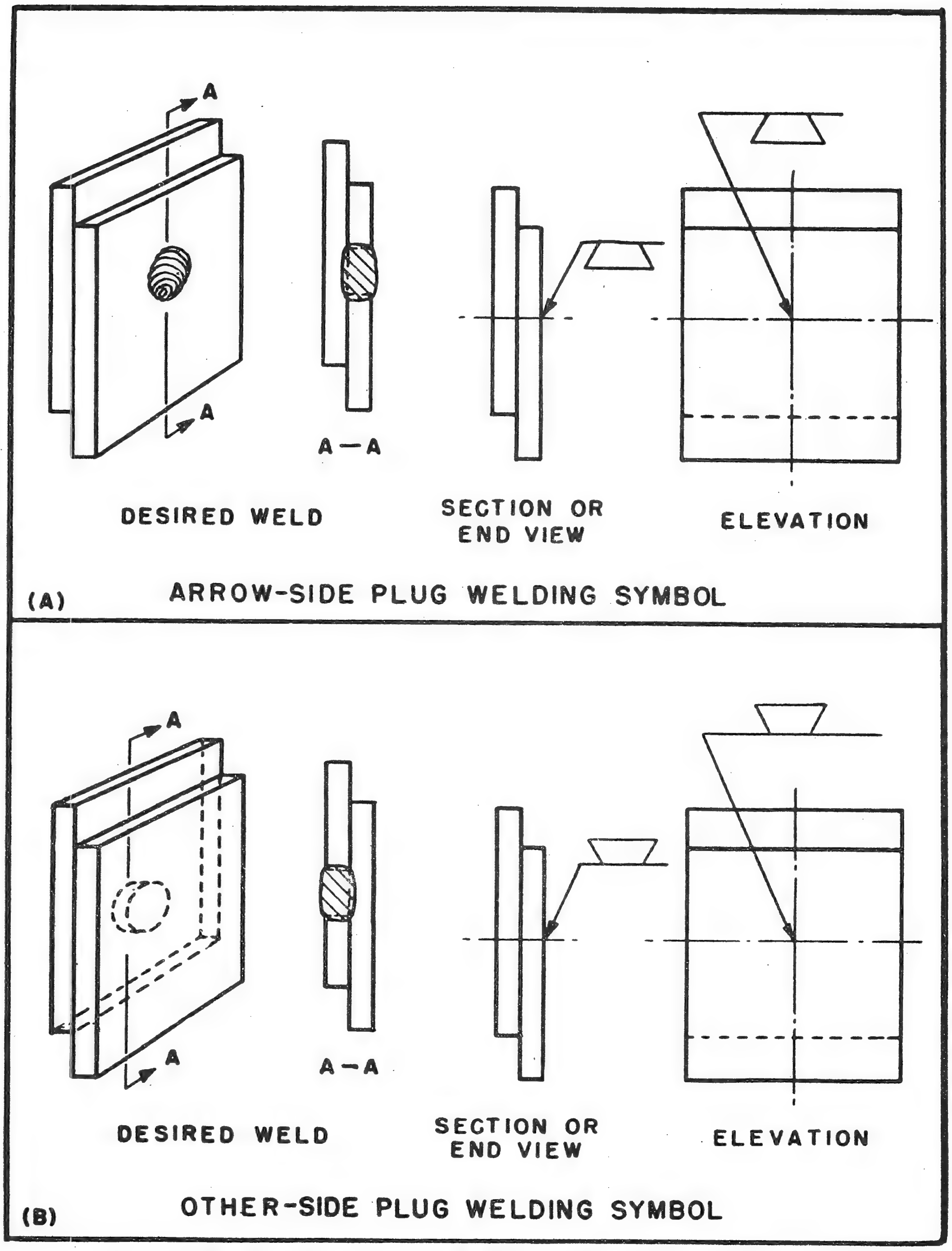


Fig. 15—Application of Plug Welding Symbols

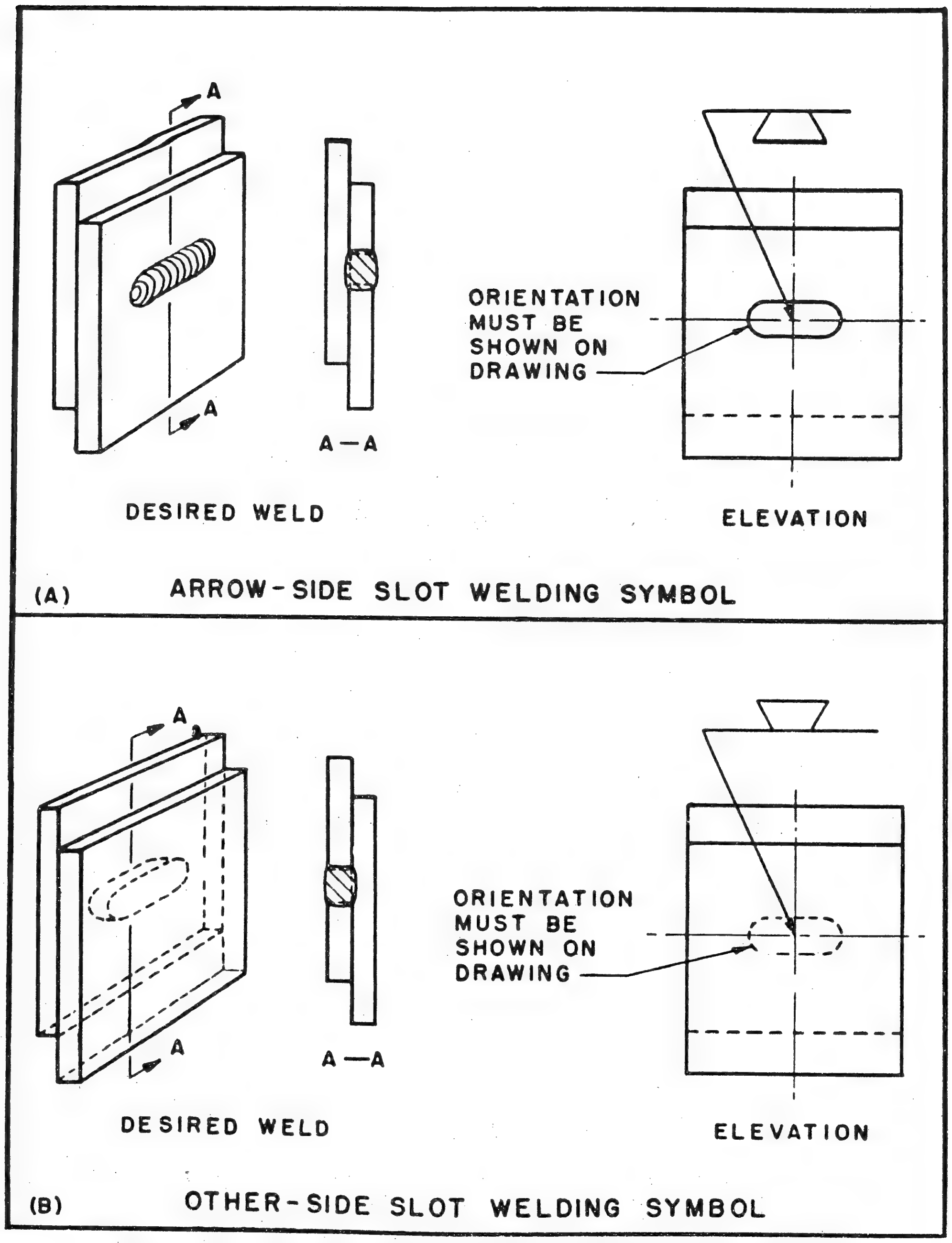


Fig. 16—Application of Slot Welding Symbols

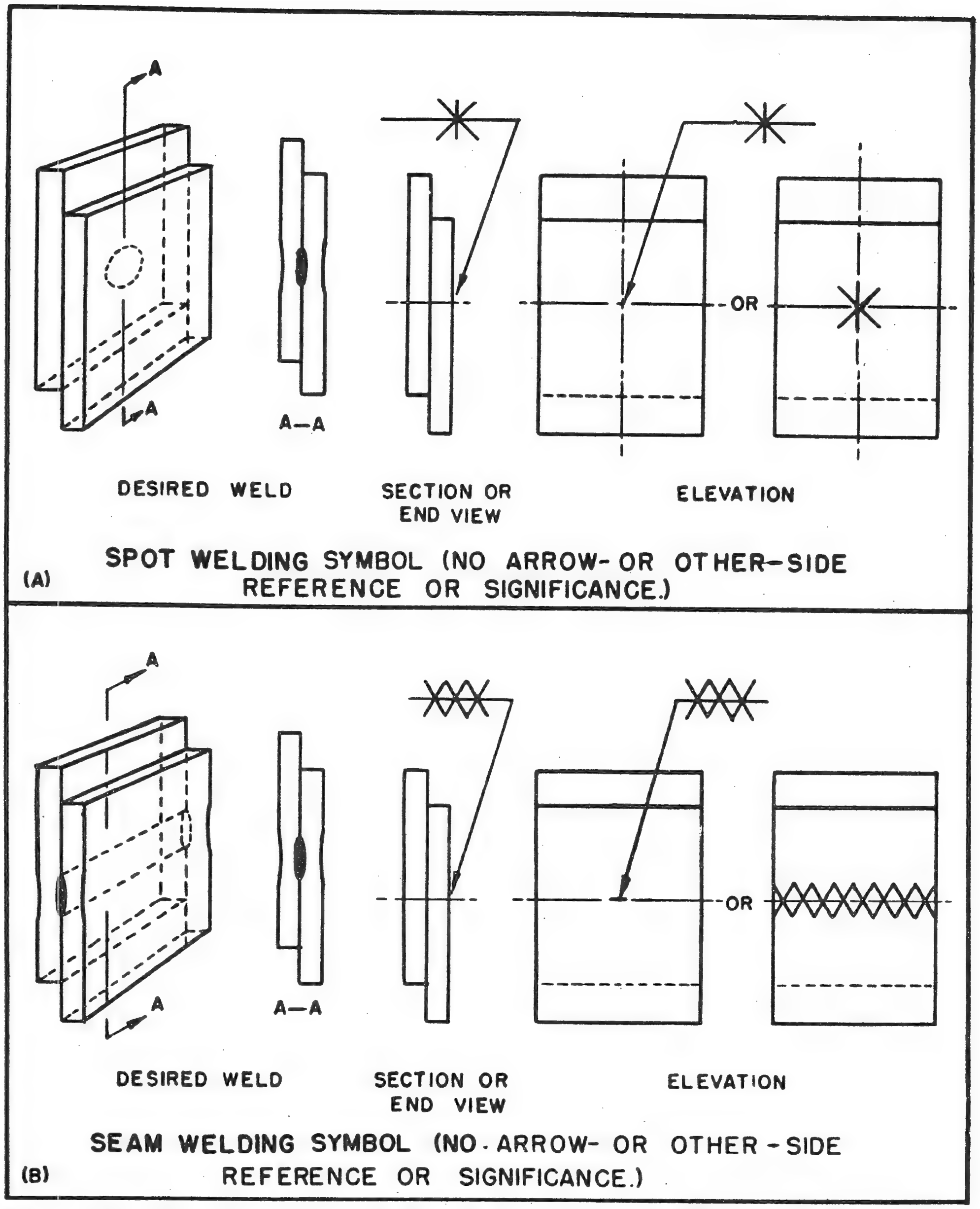


Fig. 17—Application of Spot and Seam Welding Symbols

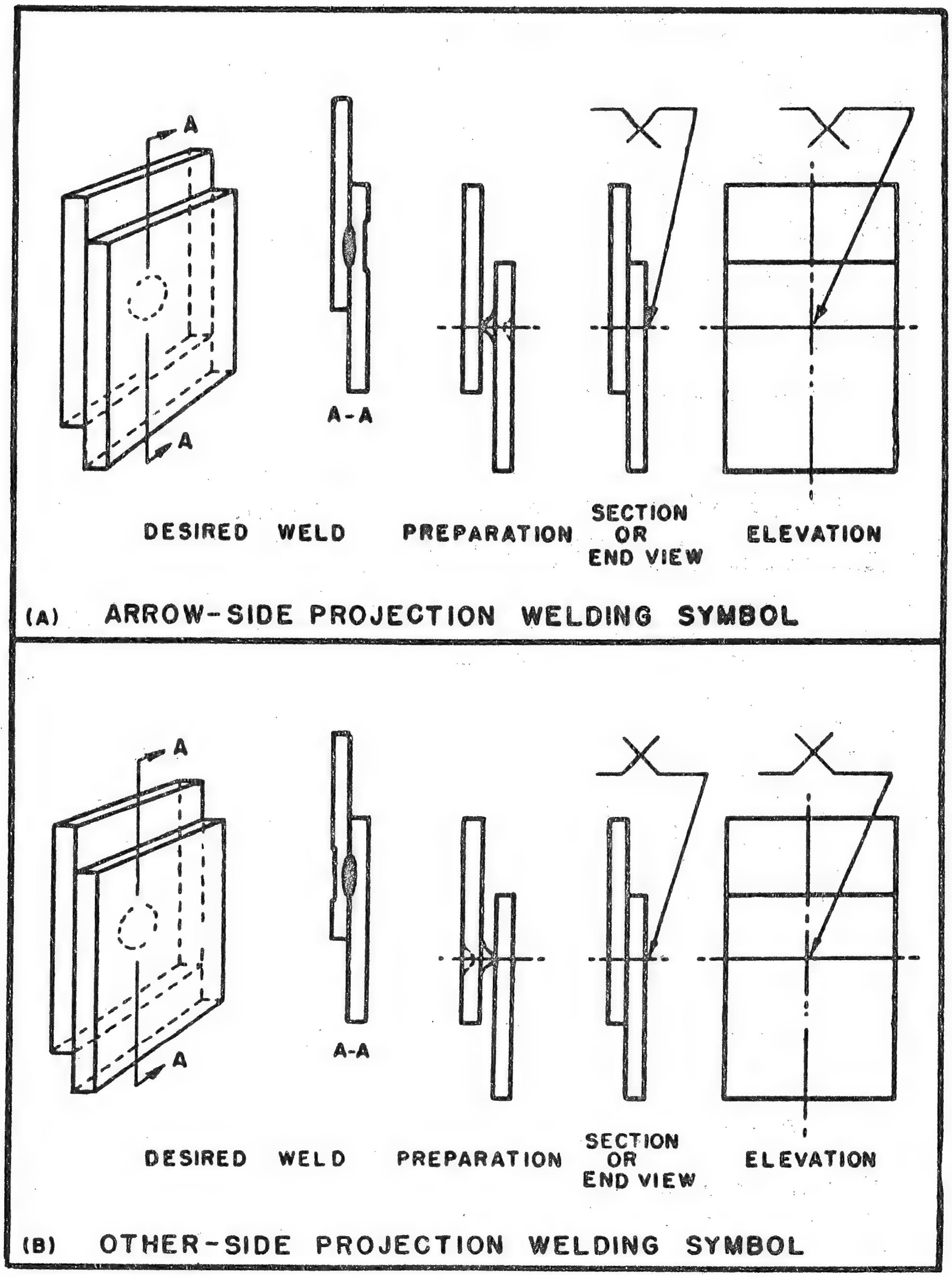


Fig. 18—Application of Projection Welding Symbols

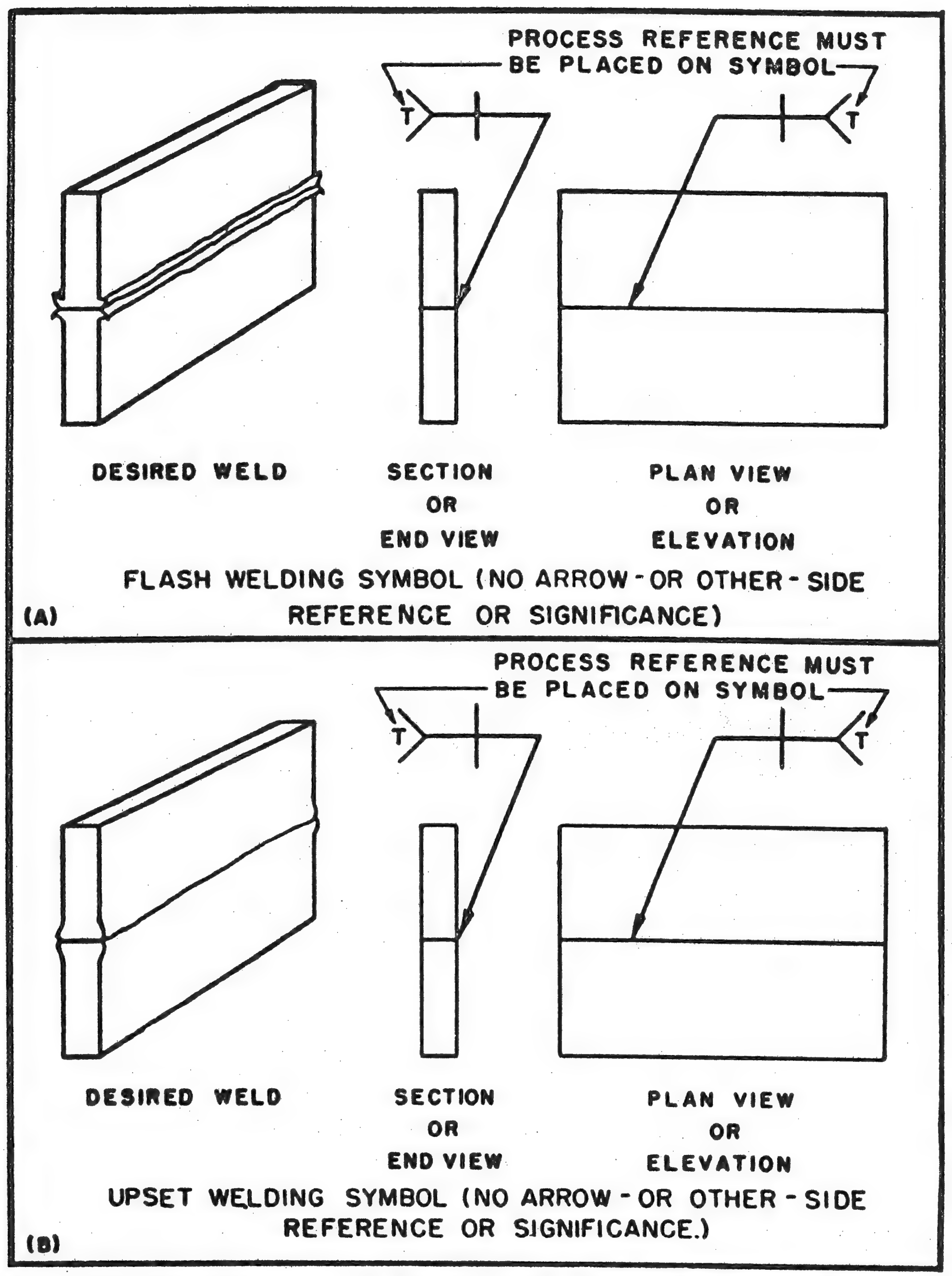


Fig. 19—Application of Flash and Upset Welding Symbols

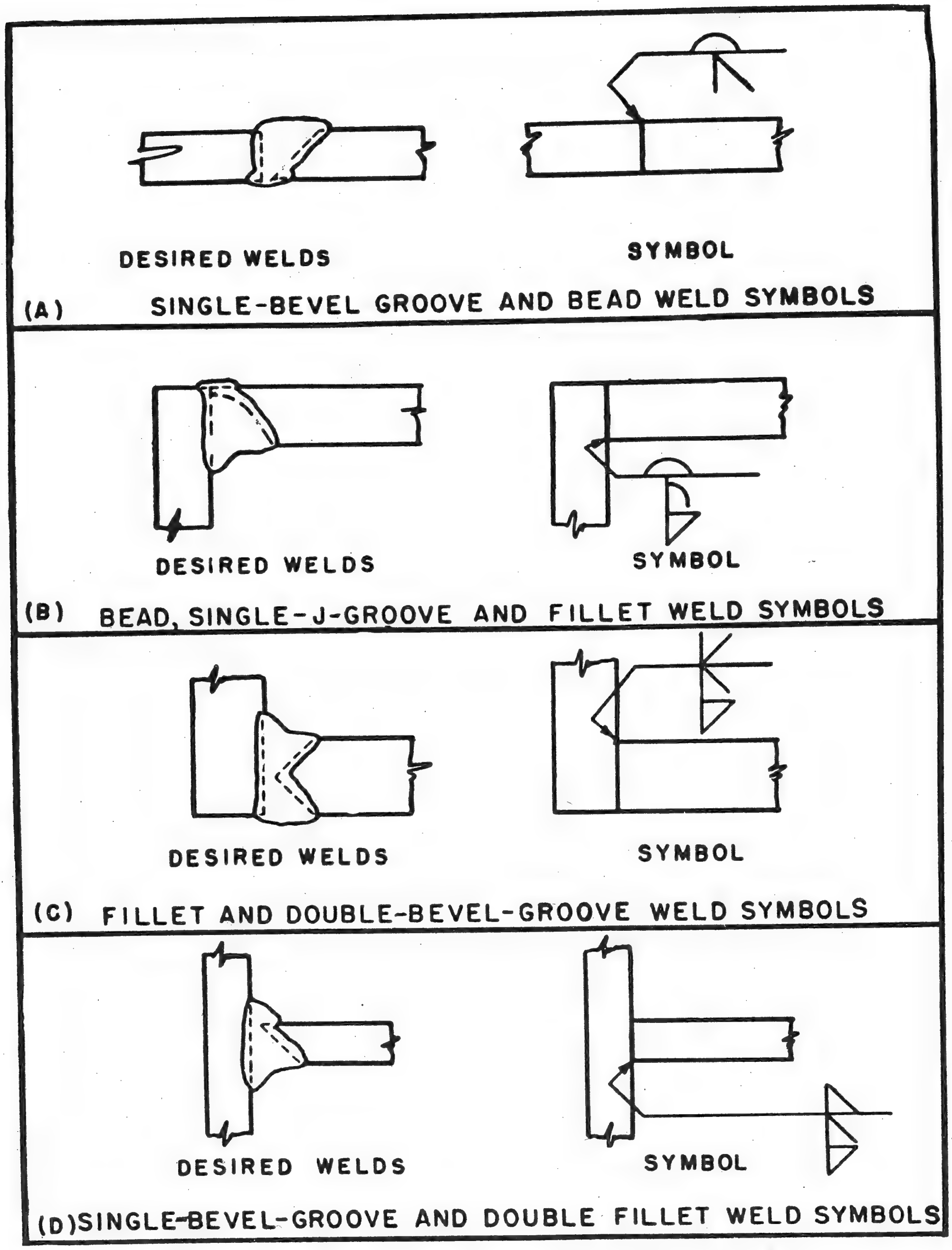


Fig. 20—Combination of Weld Symbols

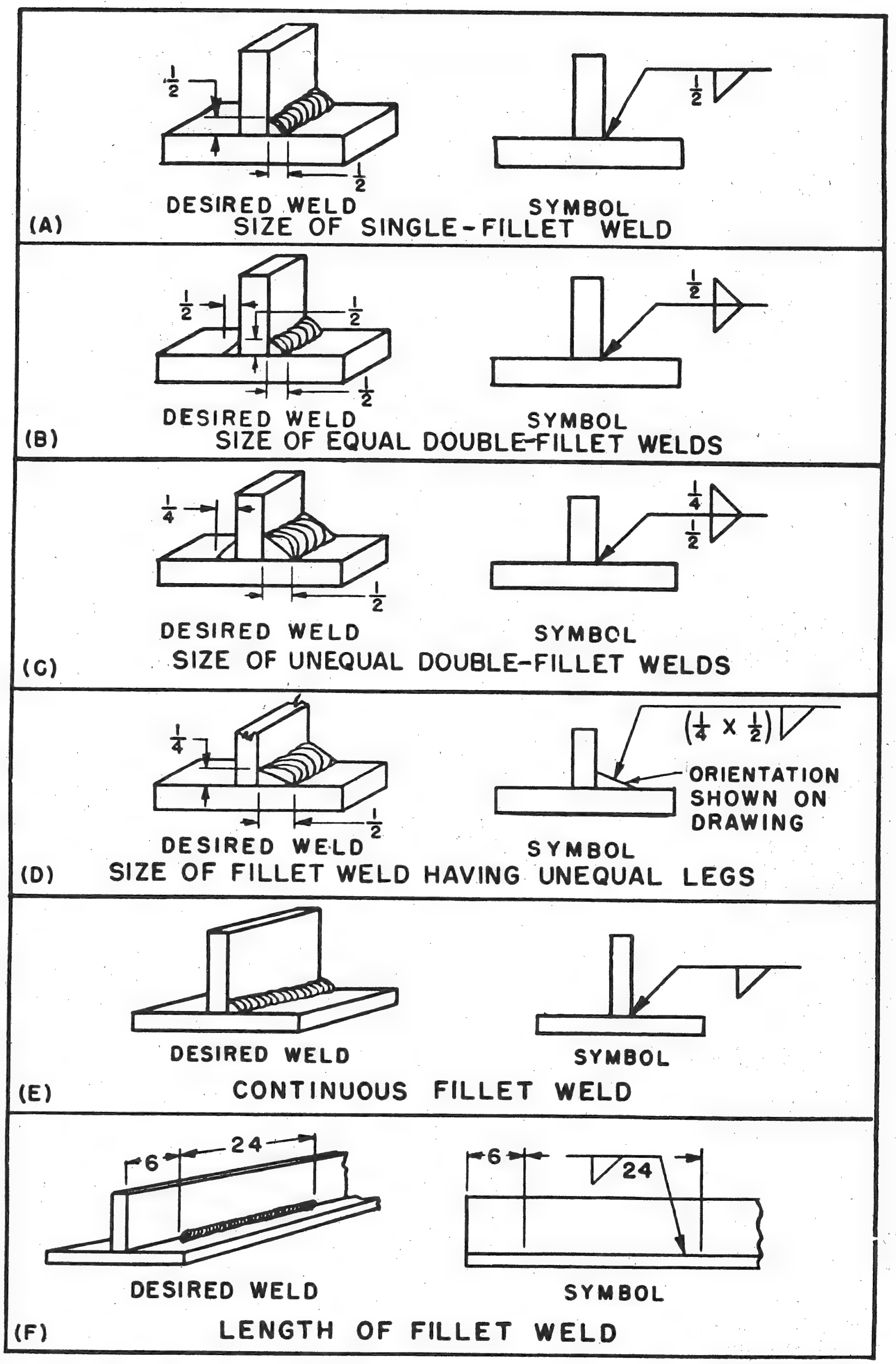


Fig. 21—Application of Dimensions to Fillet Welding Symbols

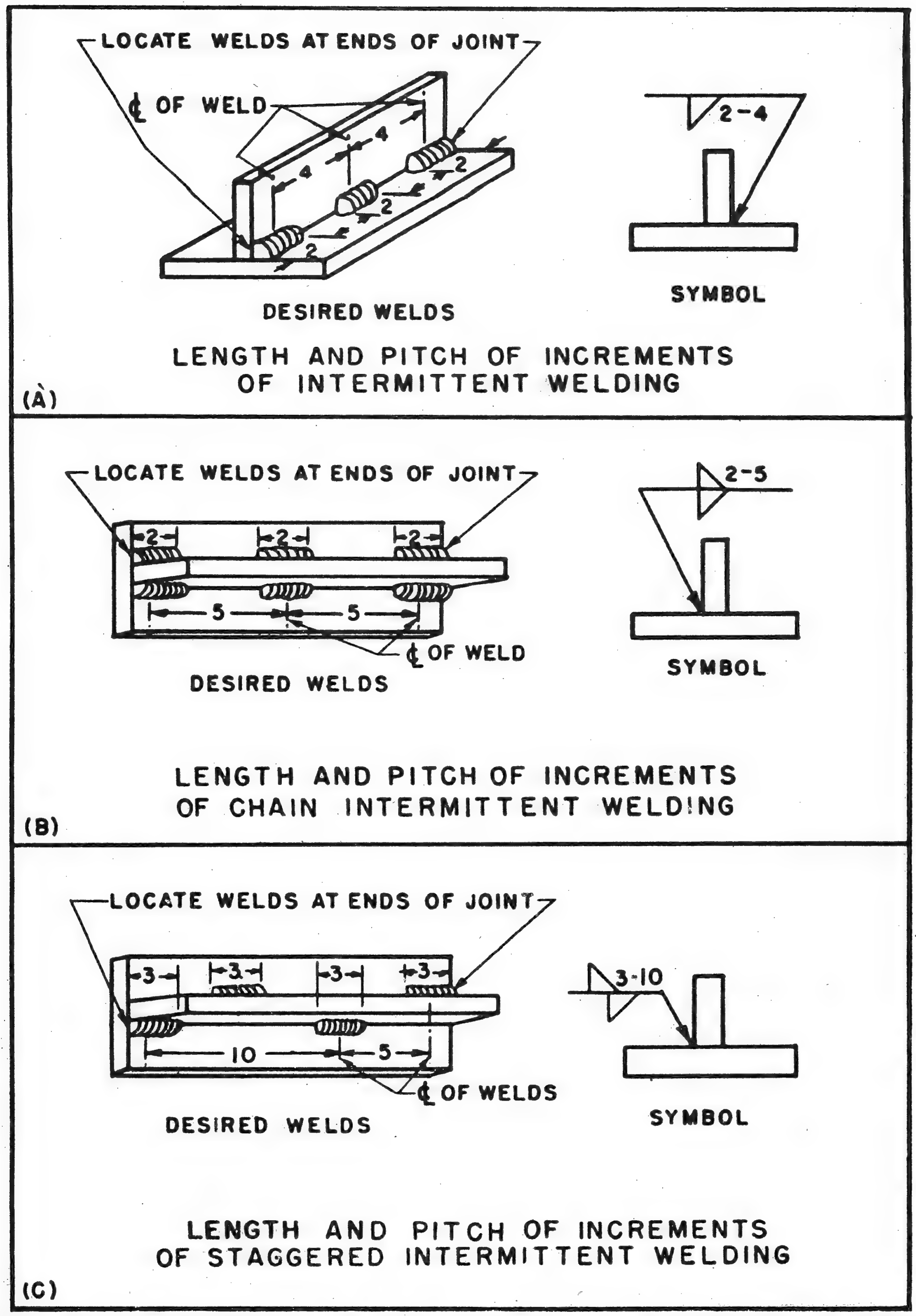


Fig. 22—Application of Dimensions to Intermittent Fillet Welding Symbols

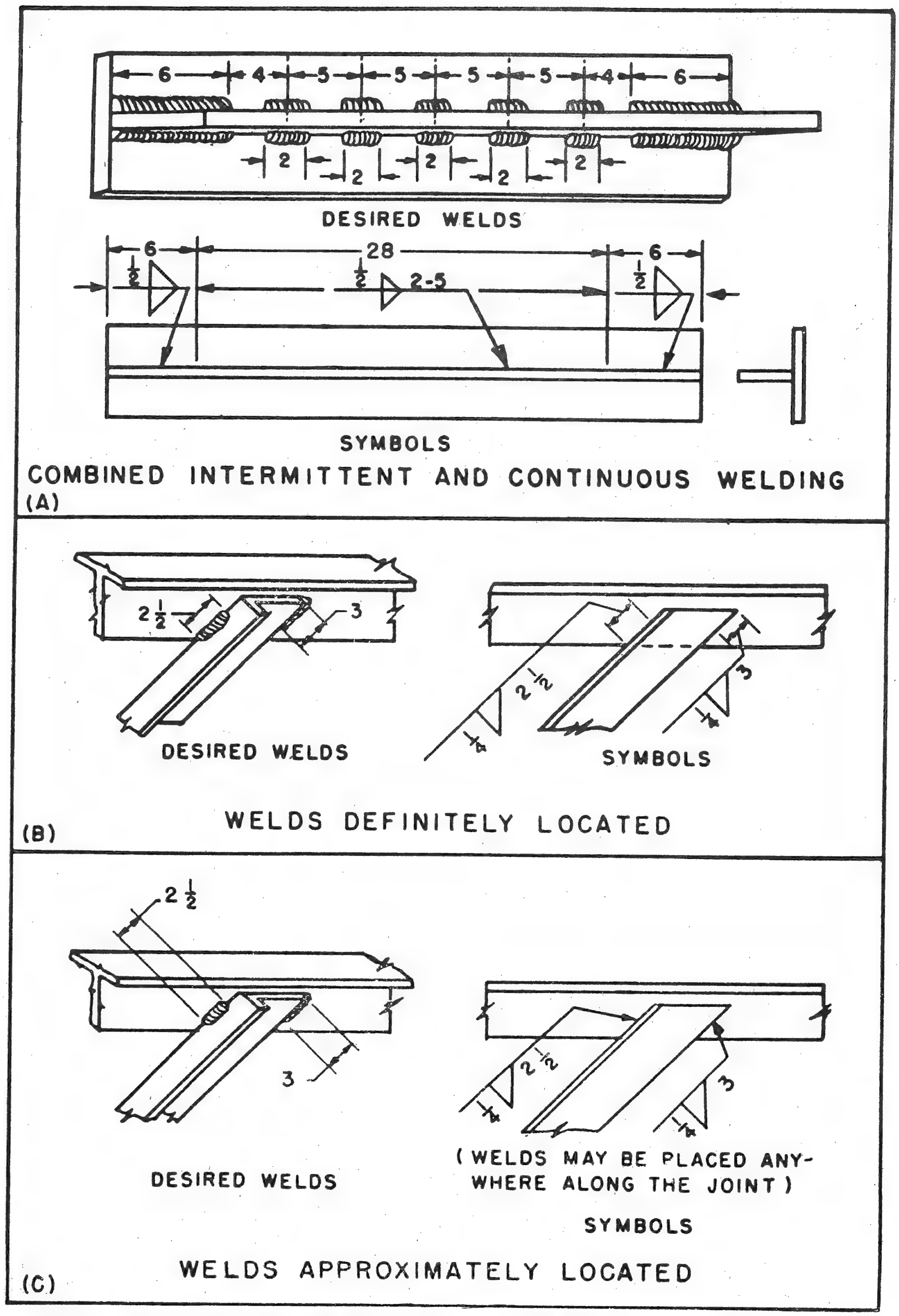


Fig. 23—Designation of Location and Extent of Fillet Welds

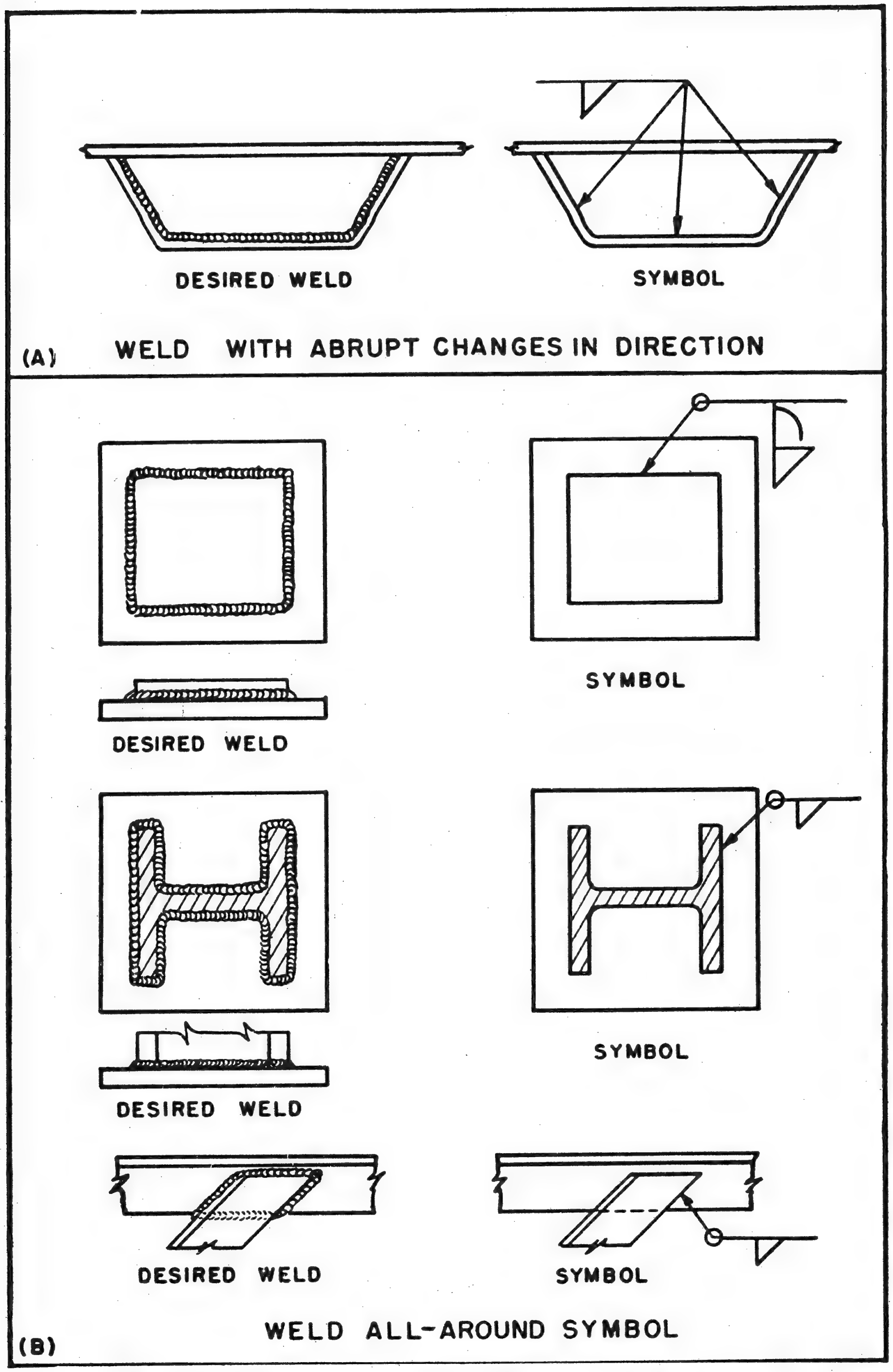


Fig. 24—Designation of Extent of Welding

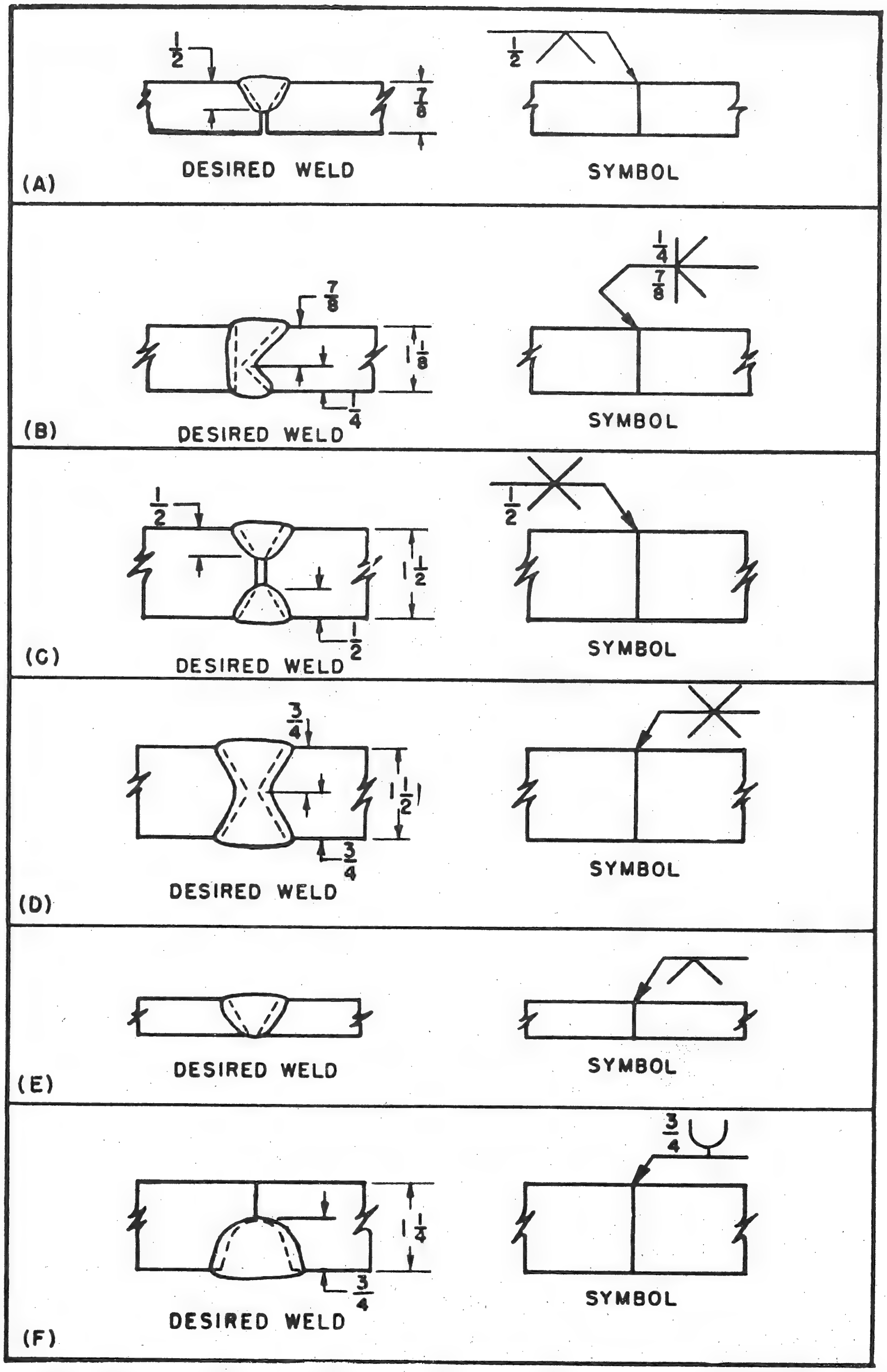


Fig. 25—Designation of Size of Groove Welds with No Specified Root Penetration

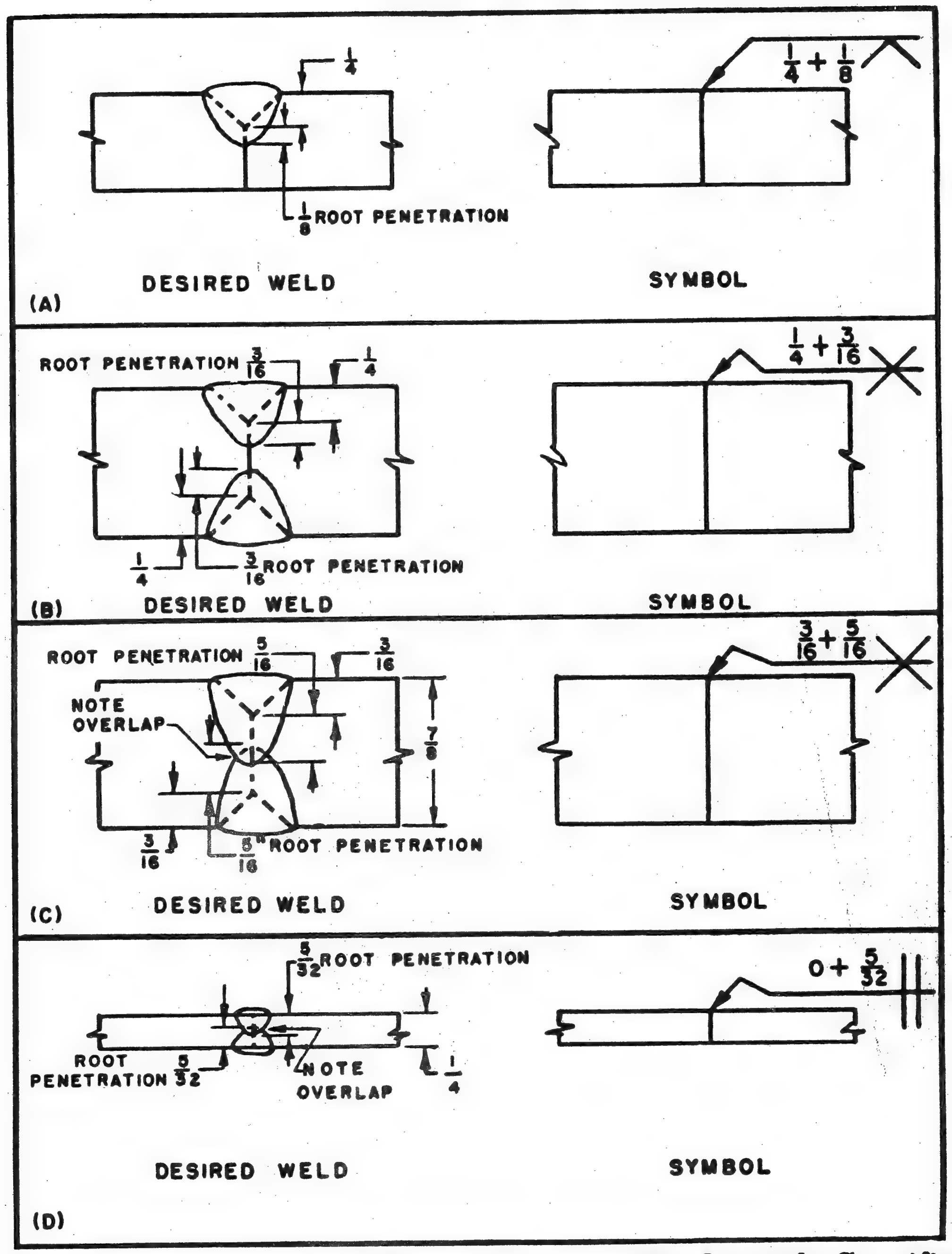


Fig. 26—Designation of Size of Groove Welds with Specified Root Penetration

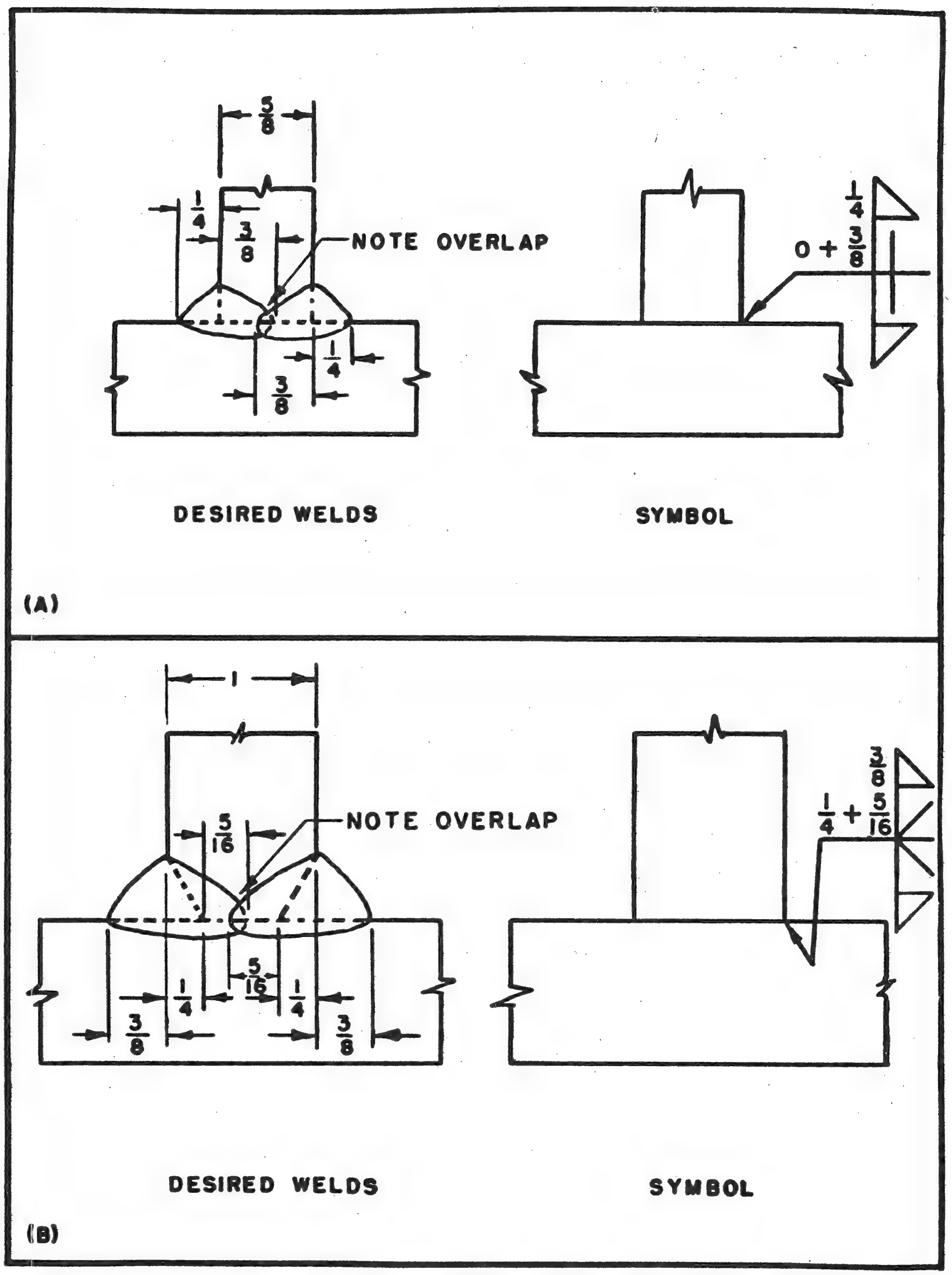


Fig. 27—Designation of Size of Combined Welds with Specified Root Penetration

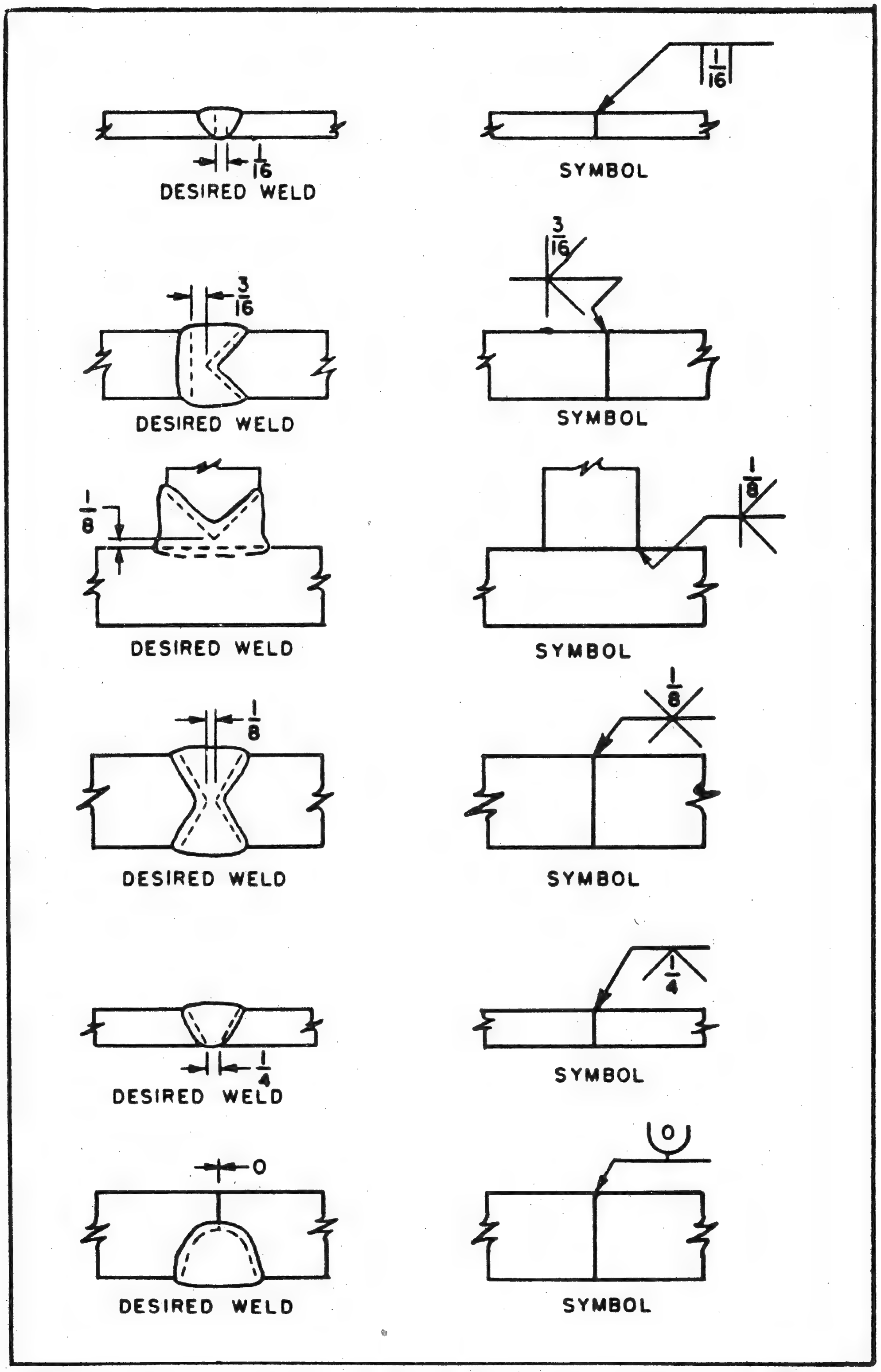


Fig. 28—Designation of Root Opening of Groove Welds

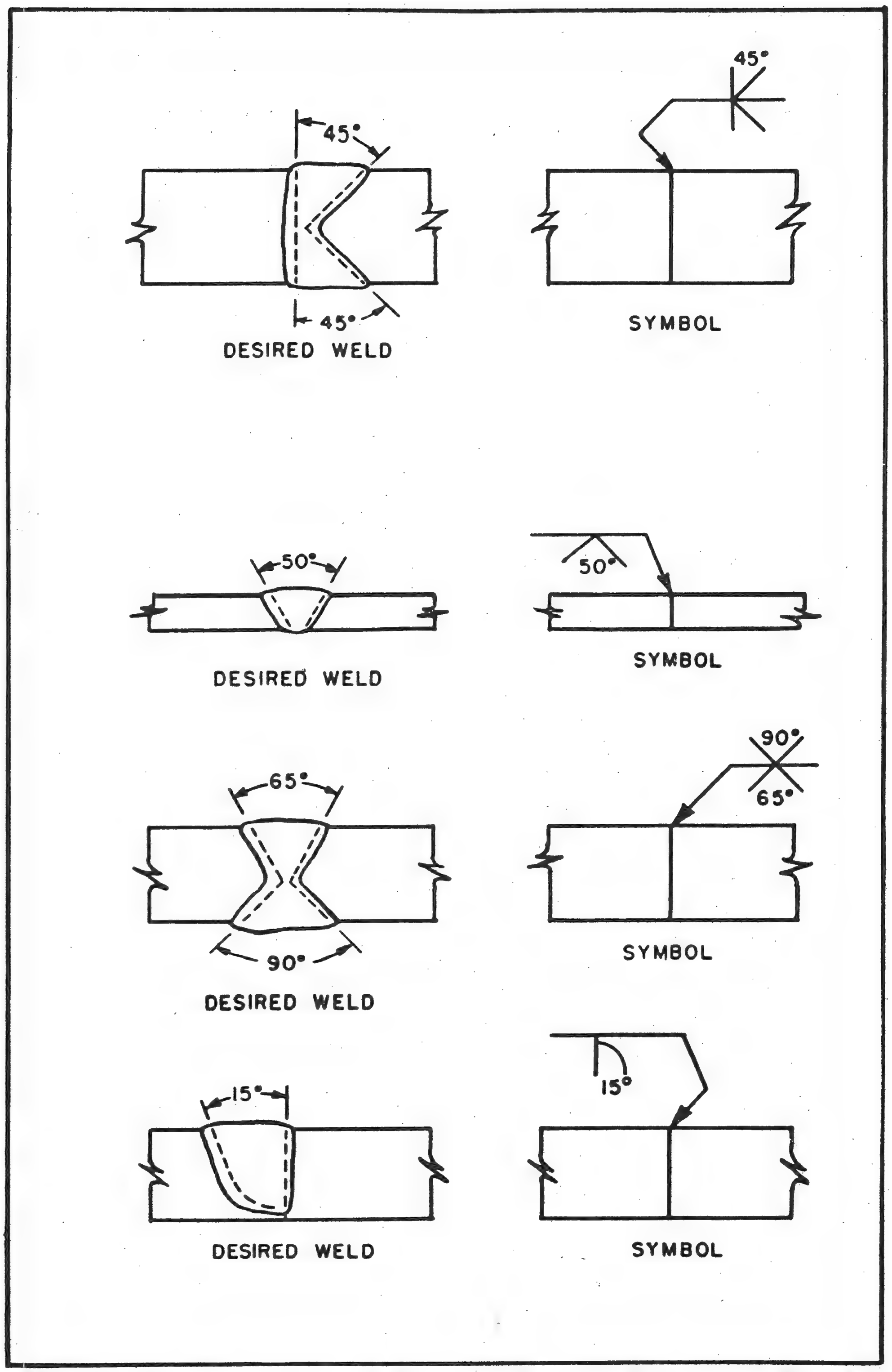


Fig. 29—Designation of Groove Angle of Groove Welds

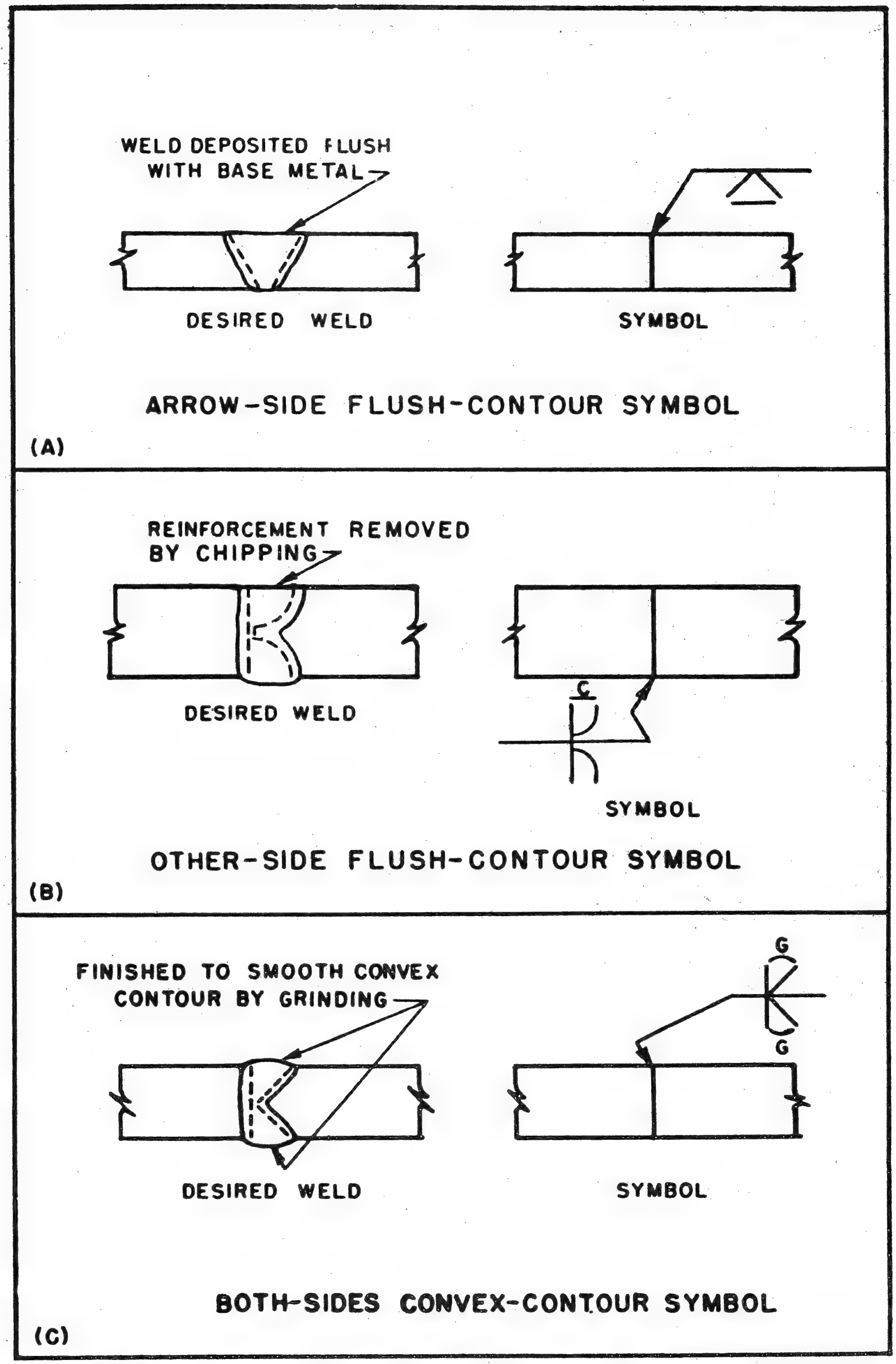


Fig. 30—Application of Flush- and Convex-Contour Symbols to Groove Welding Symbols

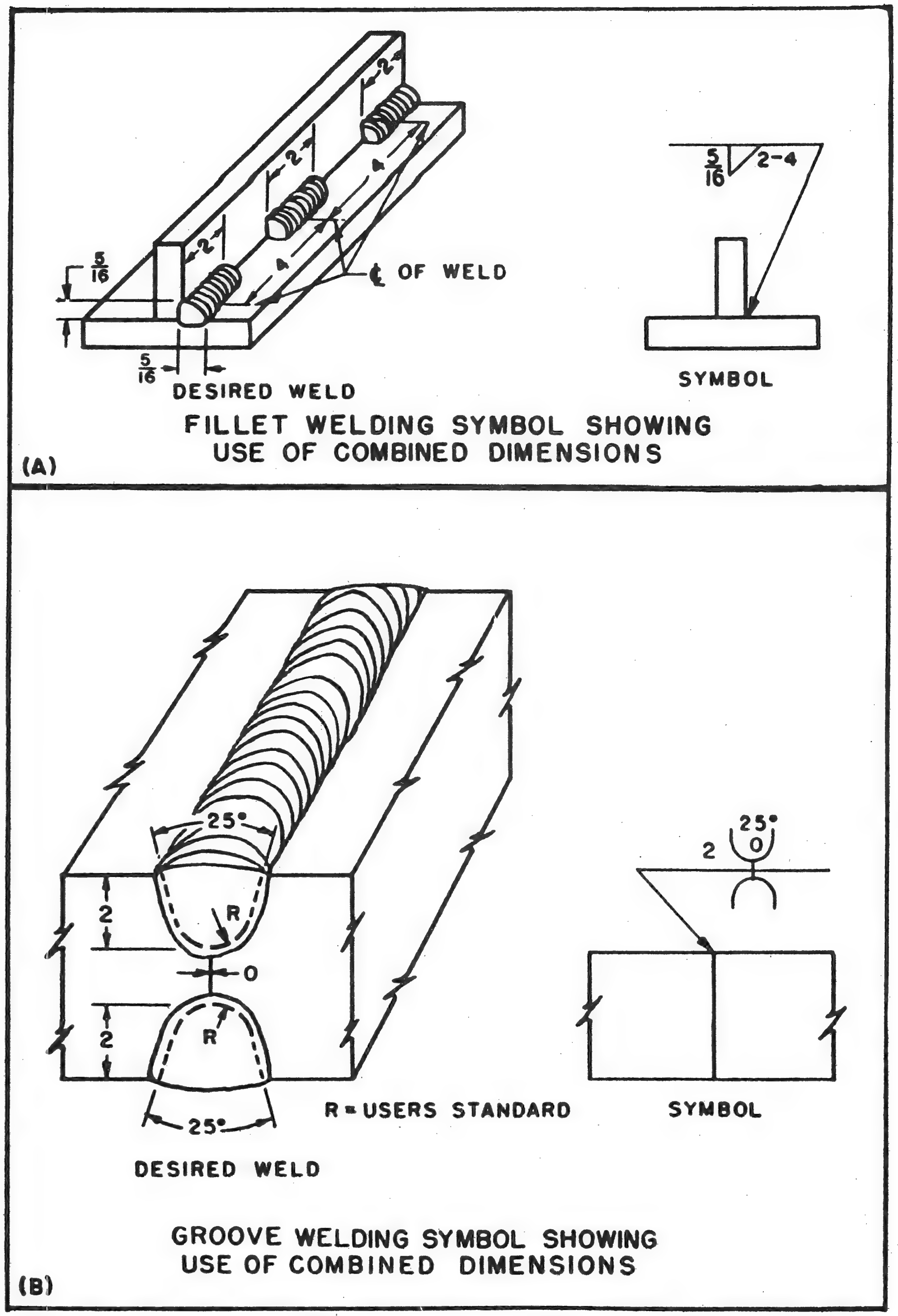


Fig. 31—Application of Dimensions to Fillet and Groove Welding Symbols

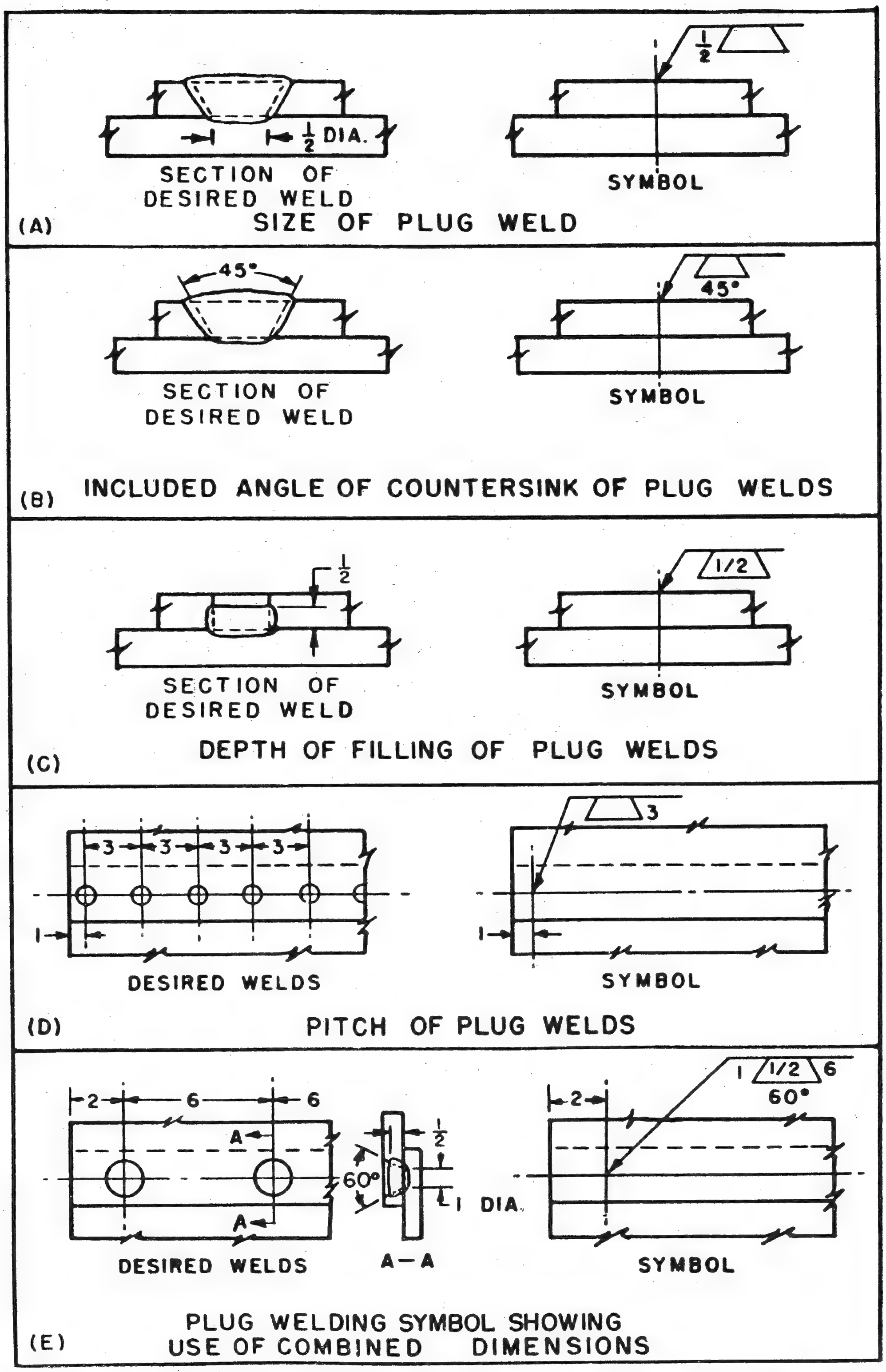


Fig. 32—Application of Dimensions to Plug Welding Symbols

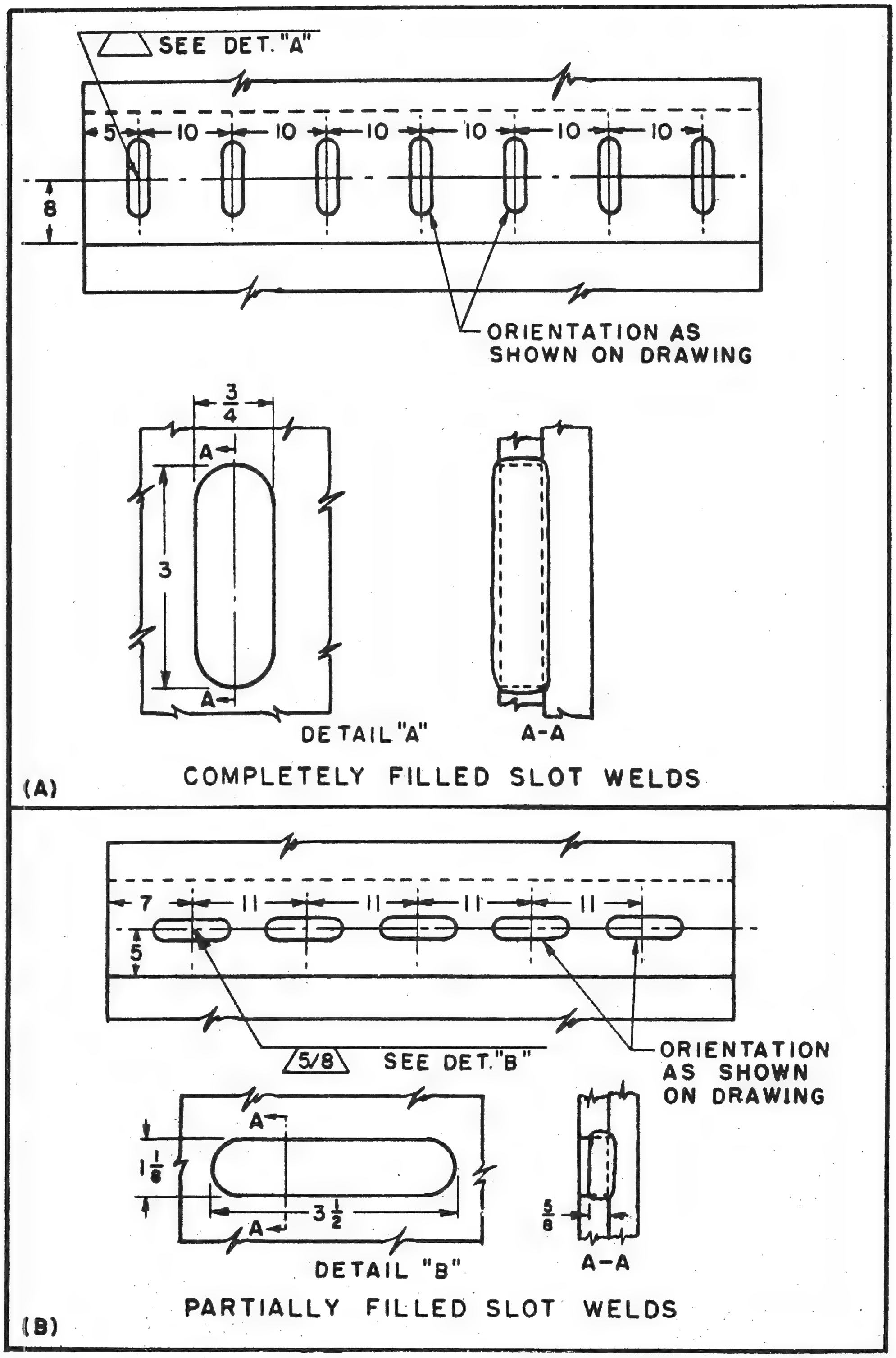


Fig. 33—Application of Dimensions to Slot Welding Symbols

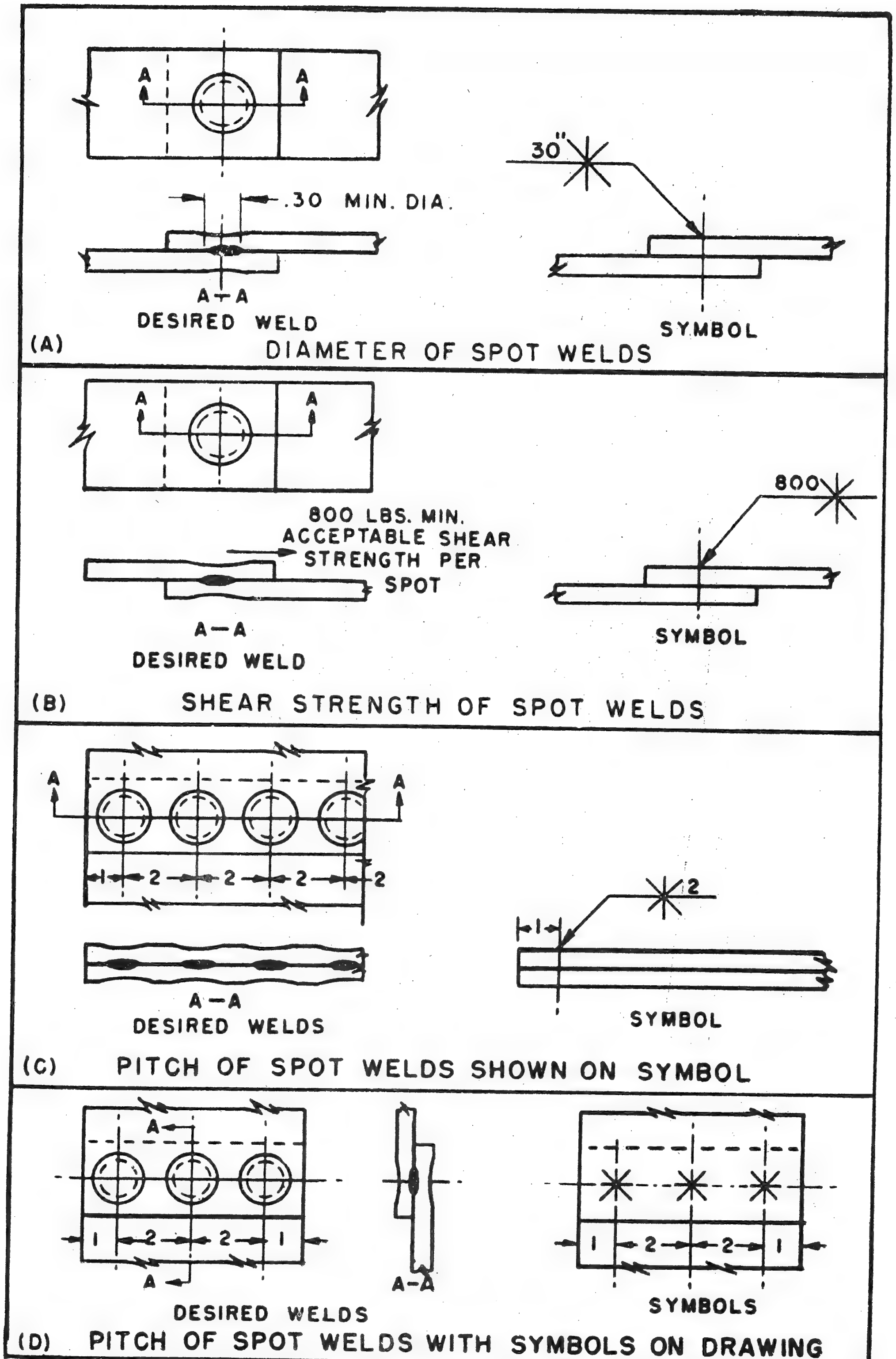


Fig. 34—Application of Dimensions to Spot Welding Symbols

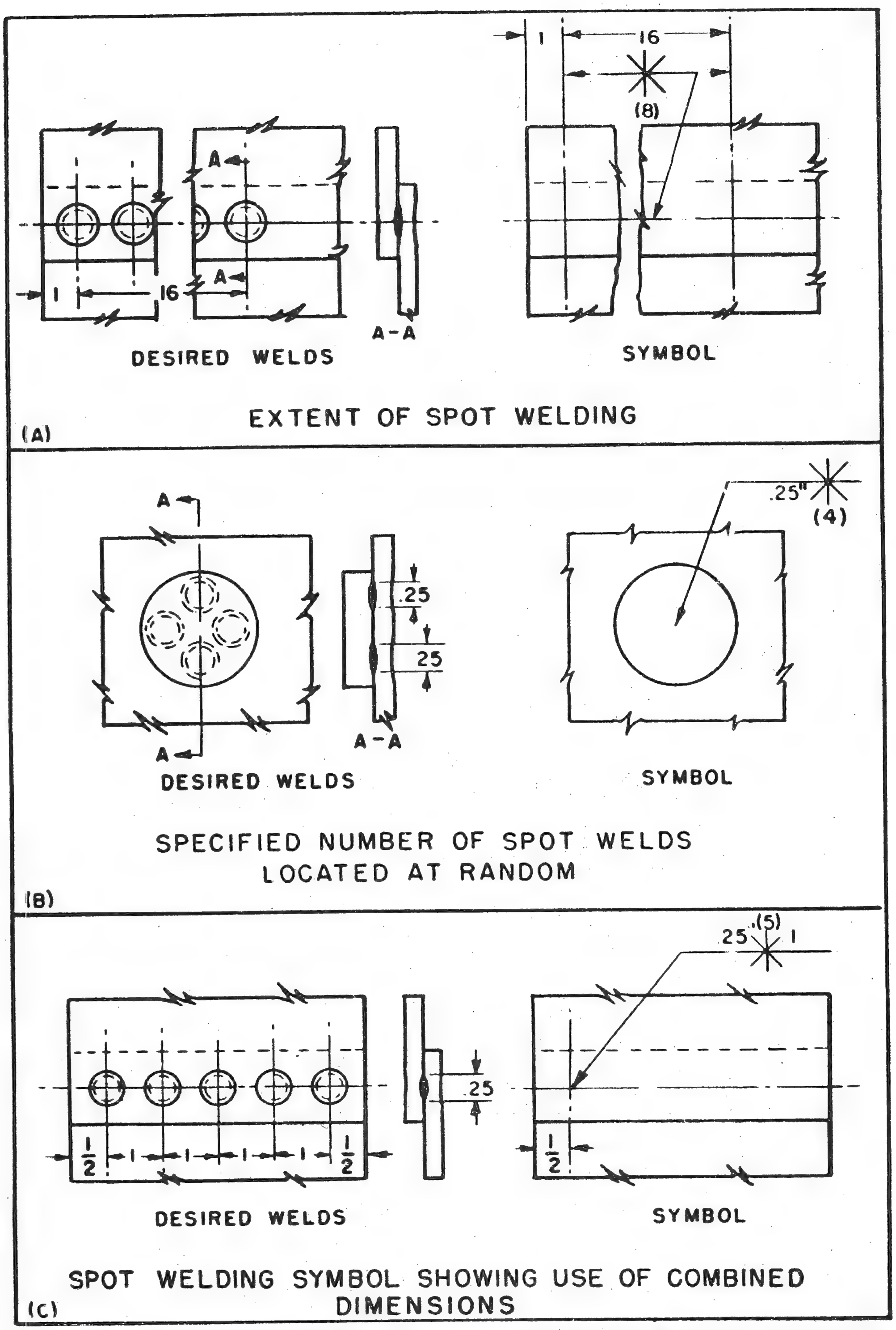


Fig. 35—Application of Dimensions to Spot Welding Symbols

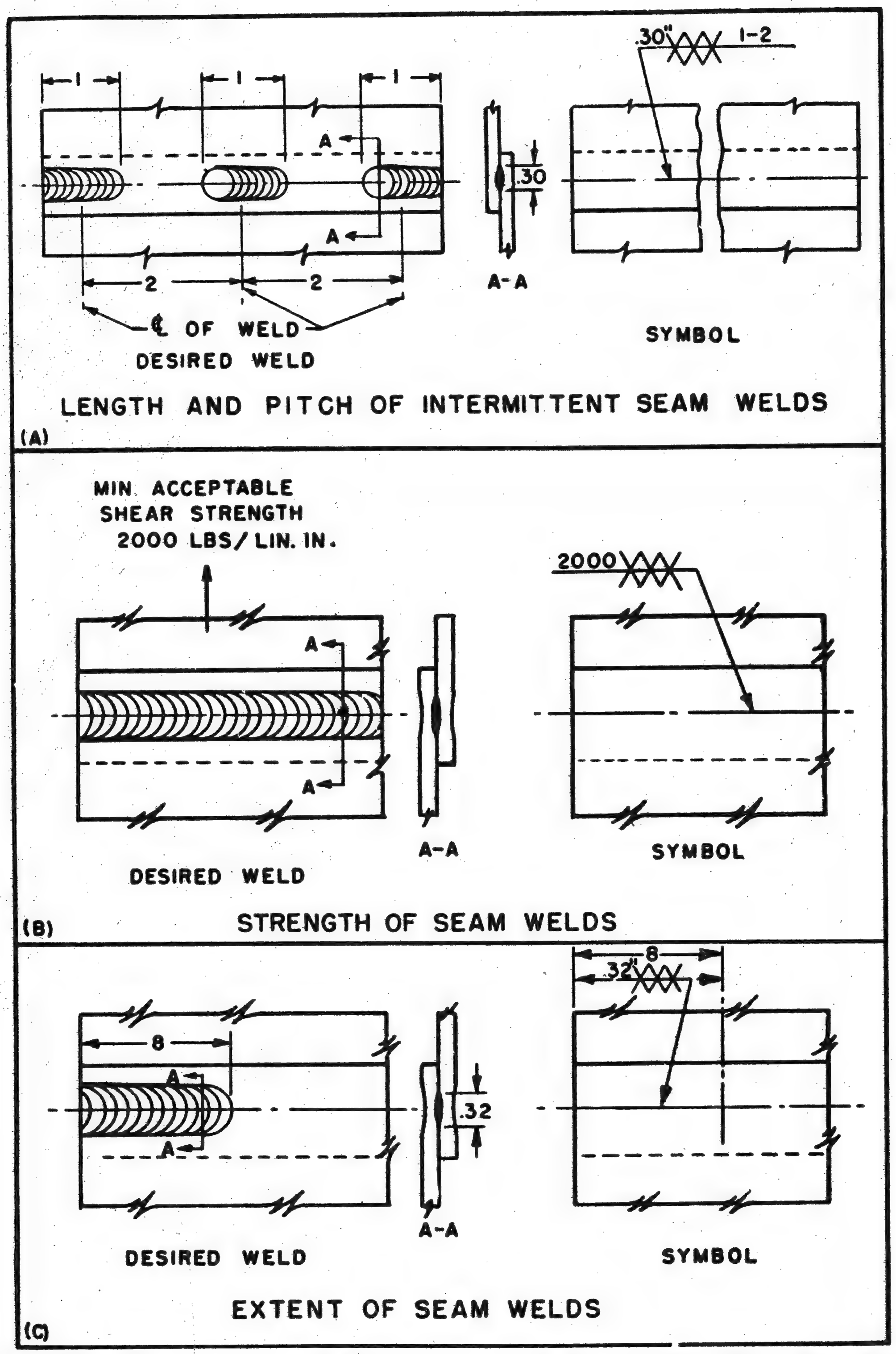


Fig. 36—Application of Dimensions to Seam Welding Symbols

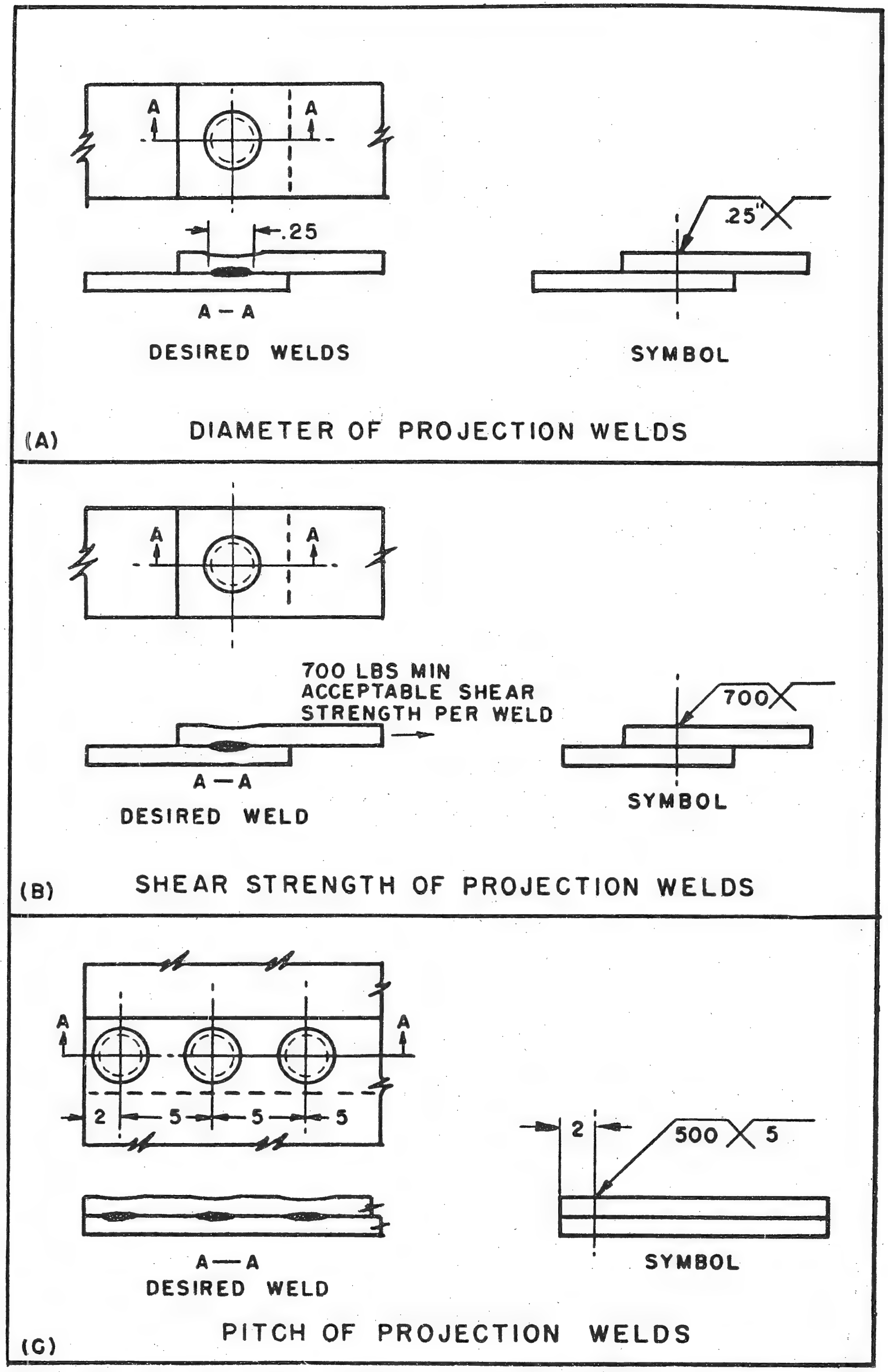


Fig. 37—Application of Dimensions to Projection Welding Symbols

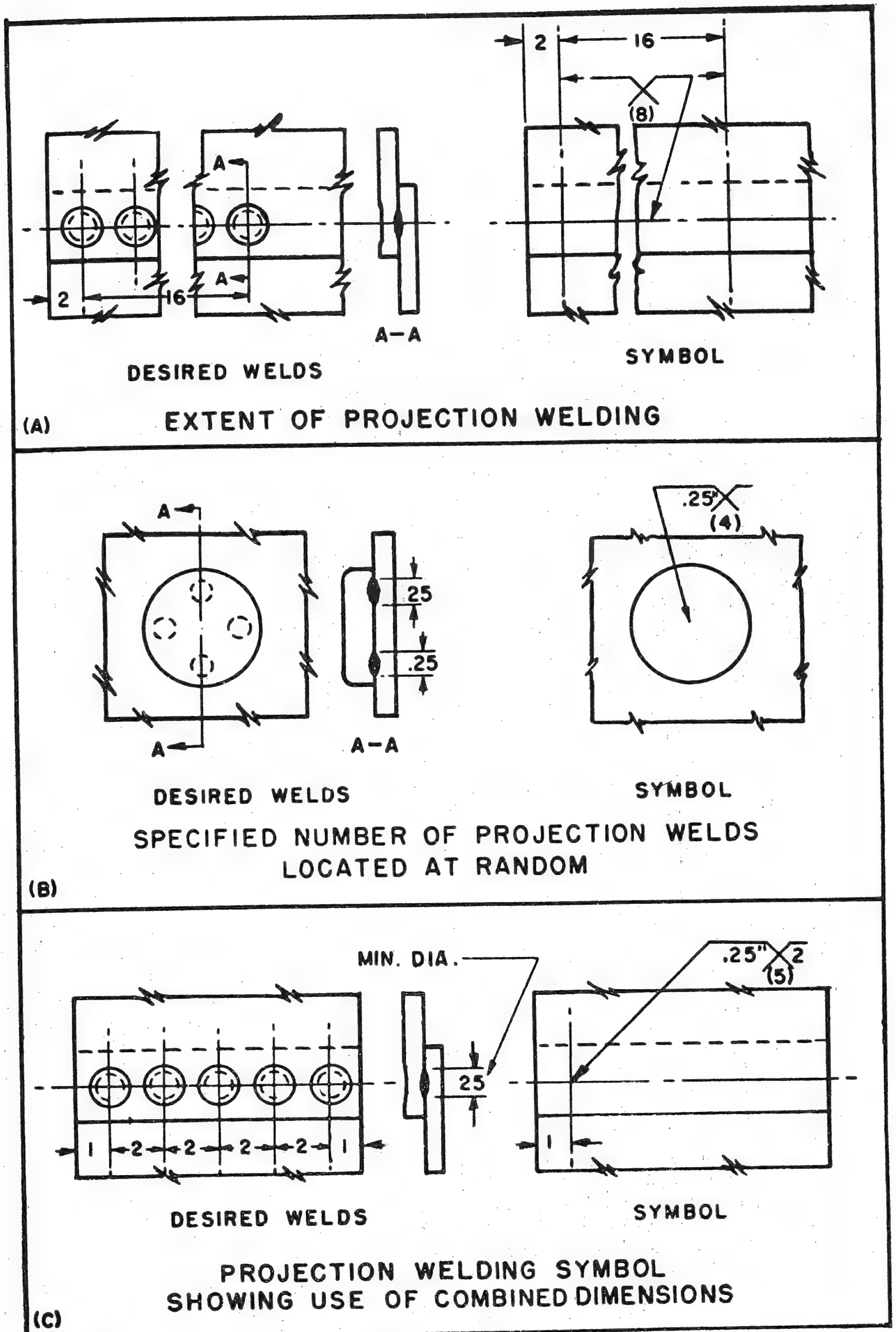


Fig. 38—Application of Dimensions to Projection Welding Symbols

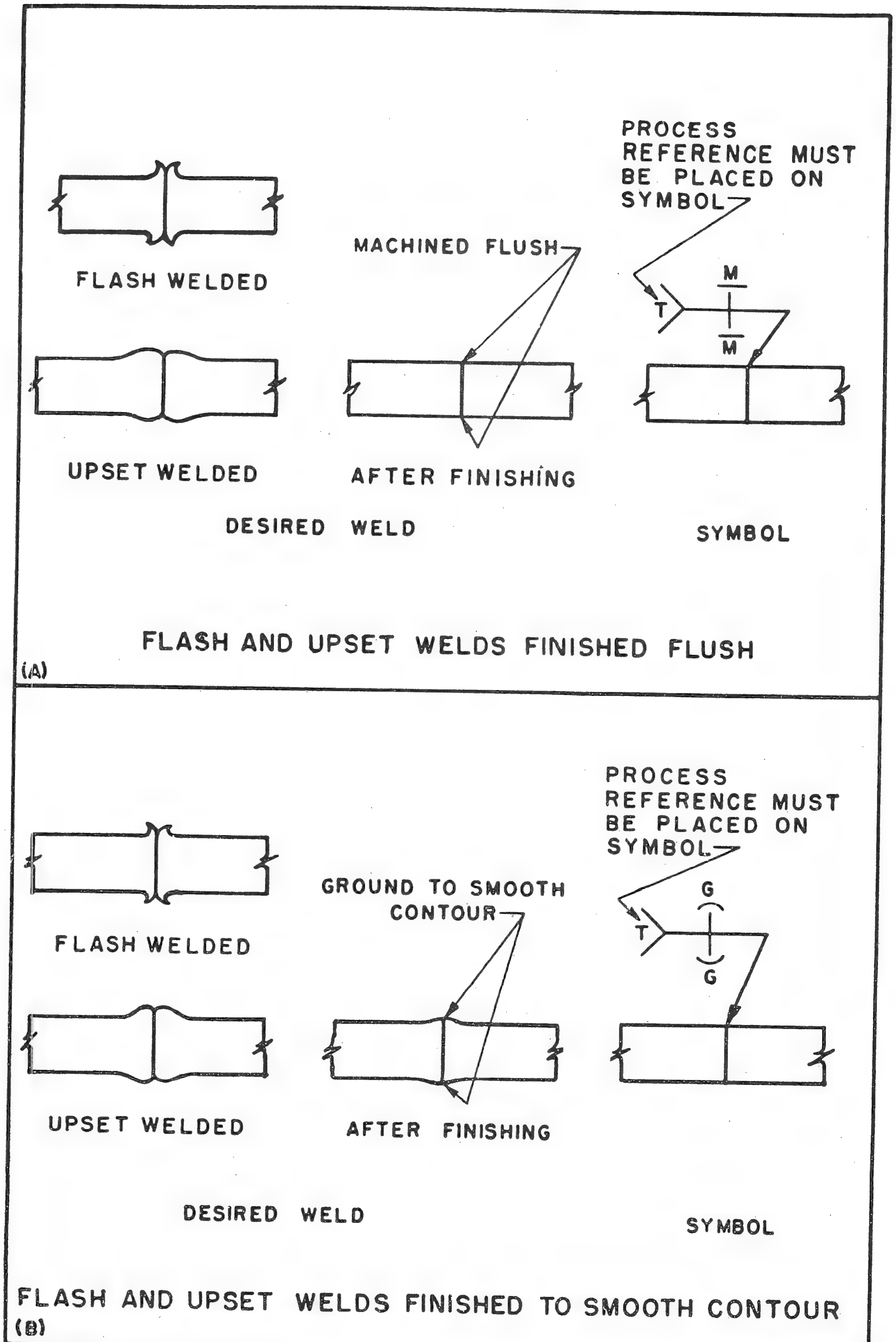


Fig. 39—Application of Flush- and Convex-Contour Symbol to Flash and Upset Welding Symbols

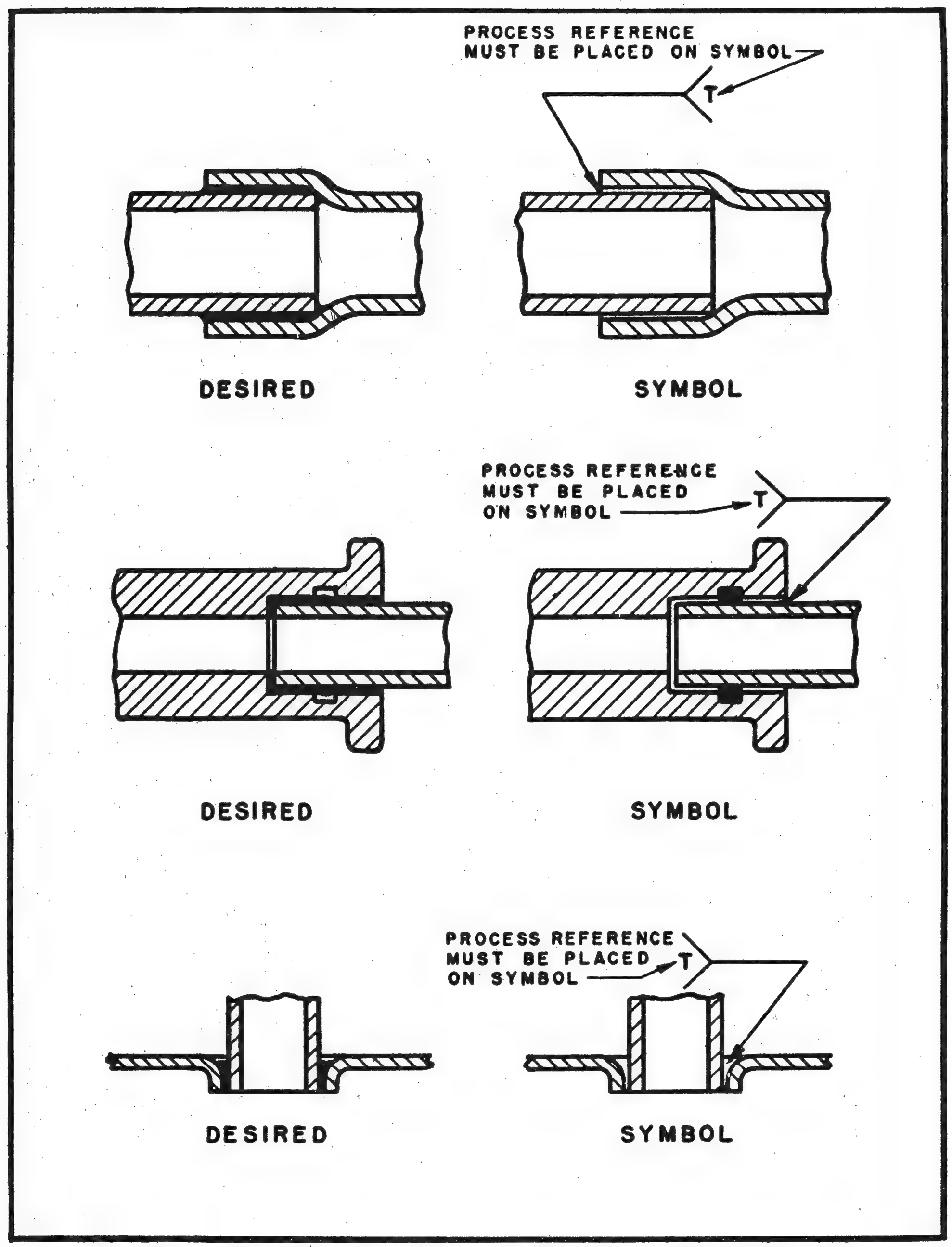


Fig. 40—Application of Brazing Symbols

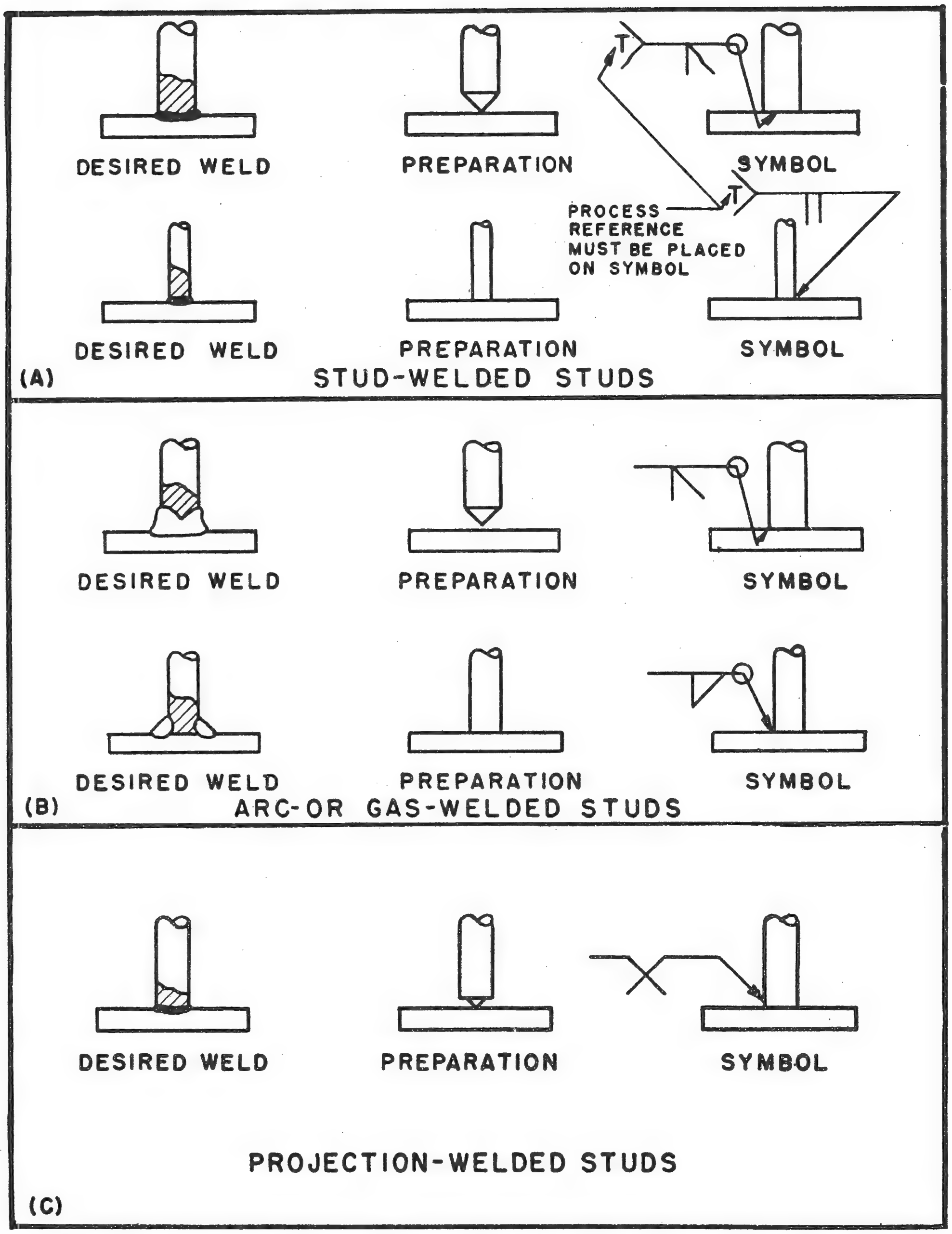


Fig. 41—Use of Welding Symbols to Indicate the Welding of Studs

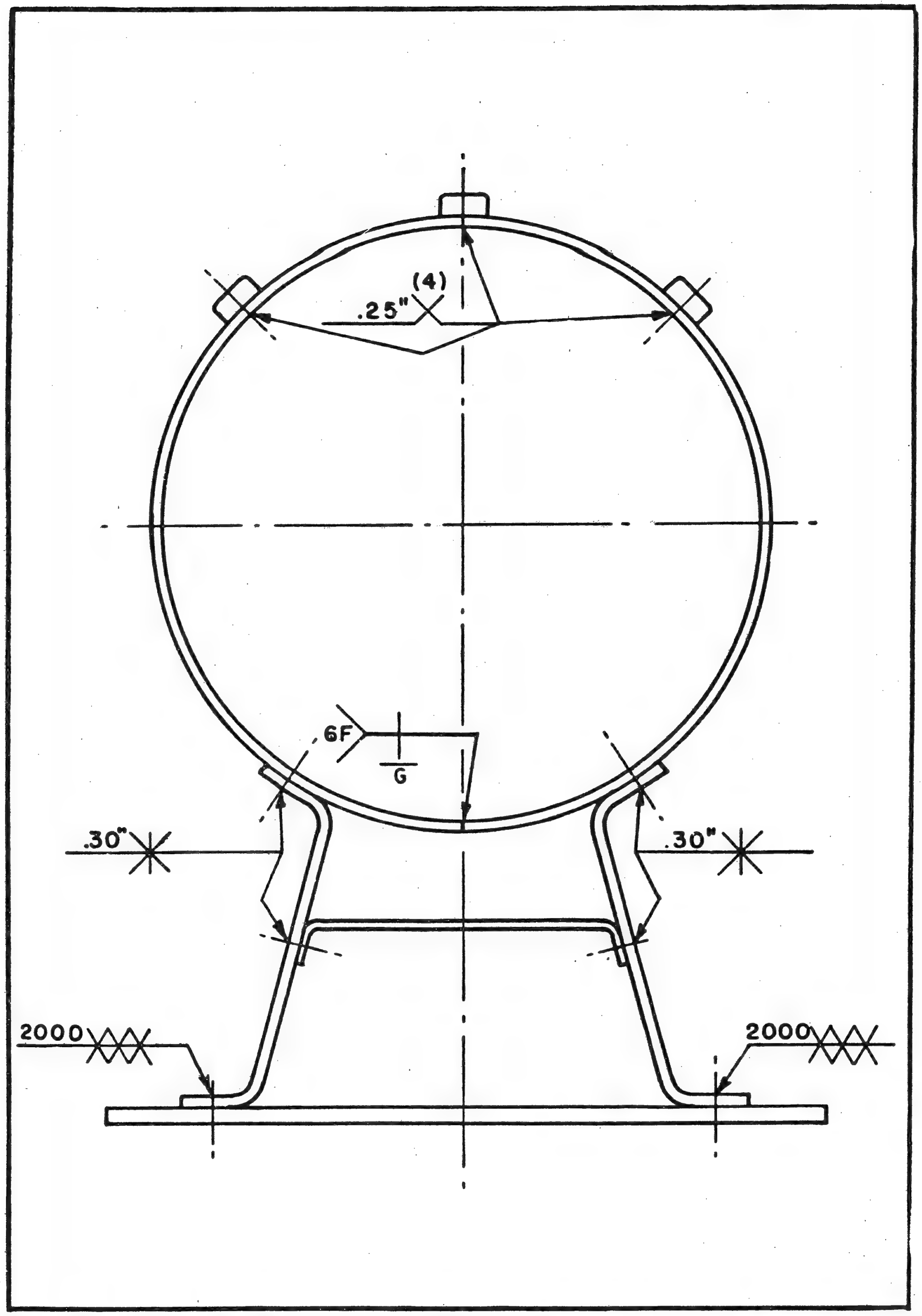


Fig. 42—Use of Resistance Welding Symbols on Sheet-Metal Fabrication Drawing

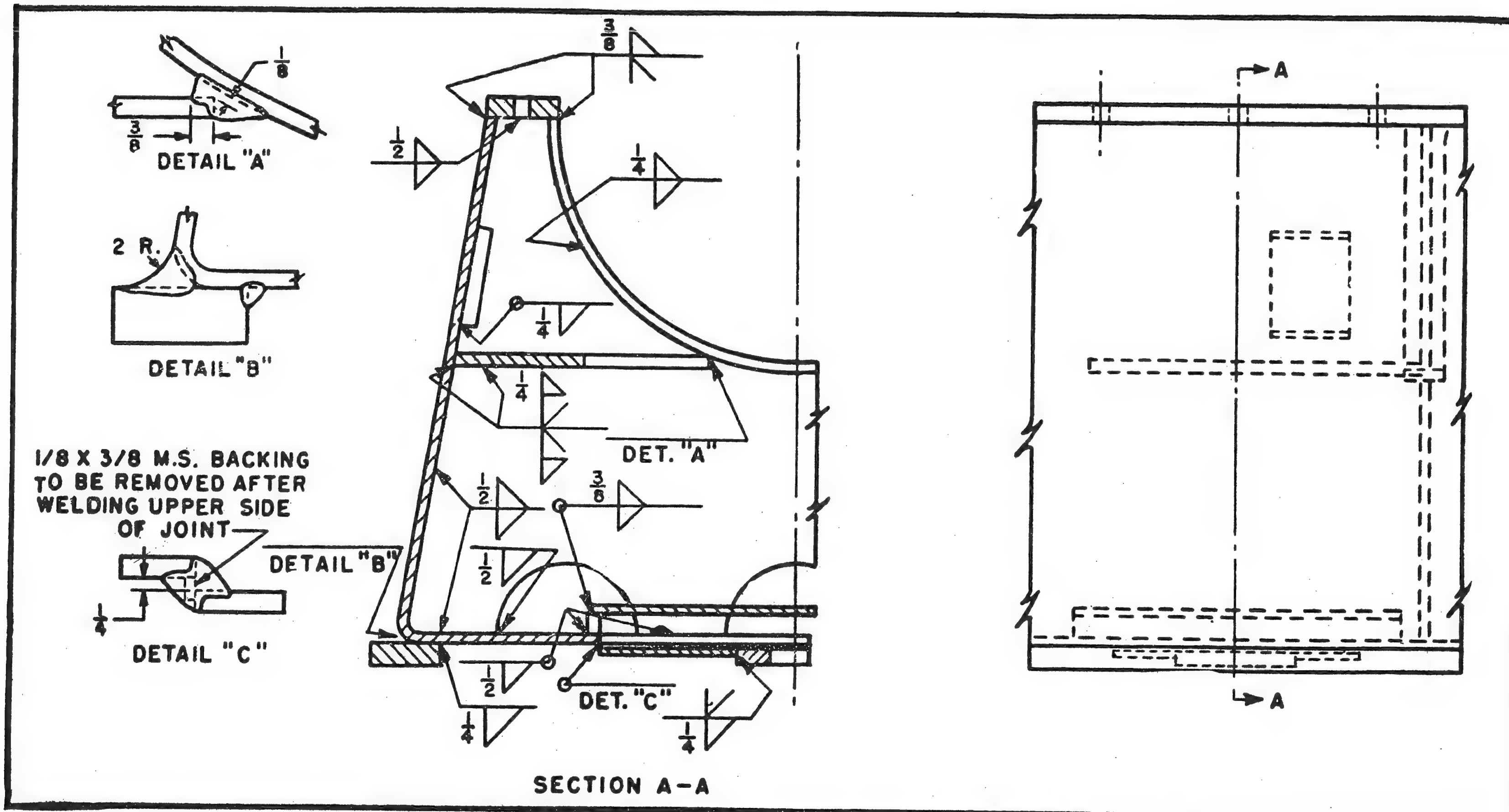


Fig. 43—Use of Arc and Gas Welding Symbols on Machinery Drawing

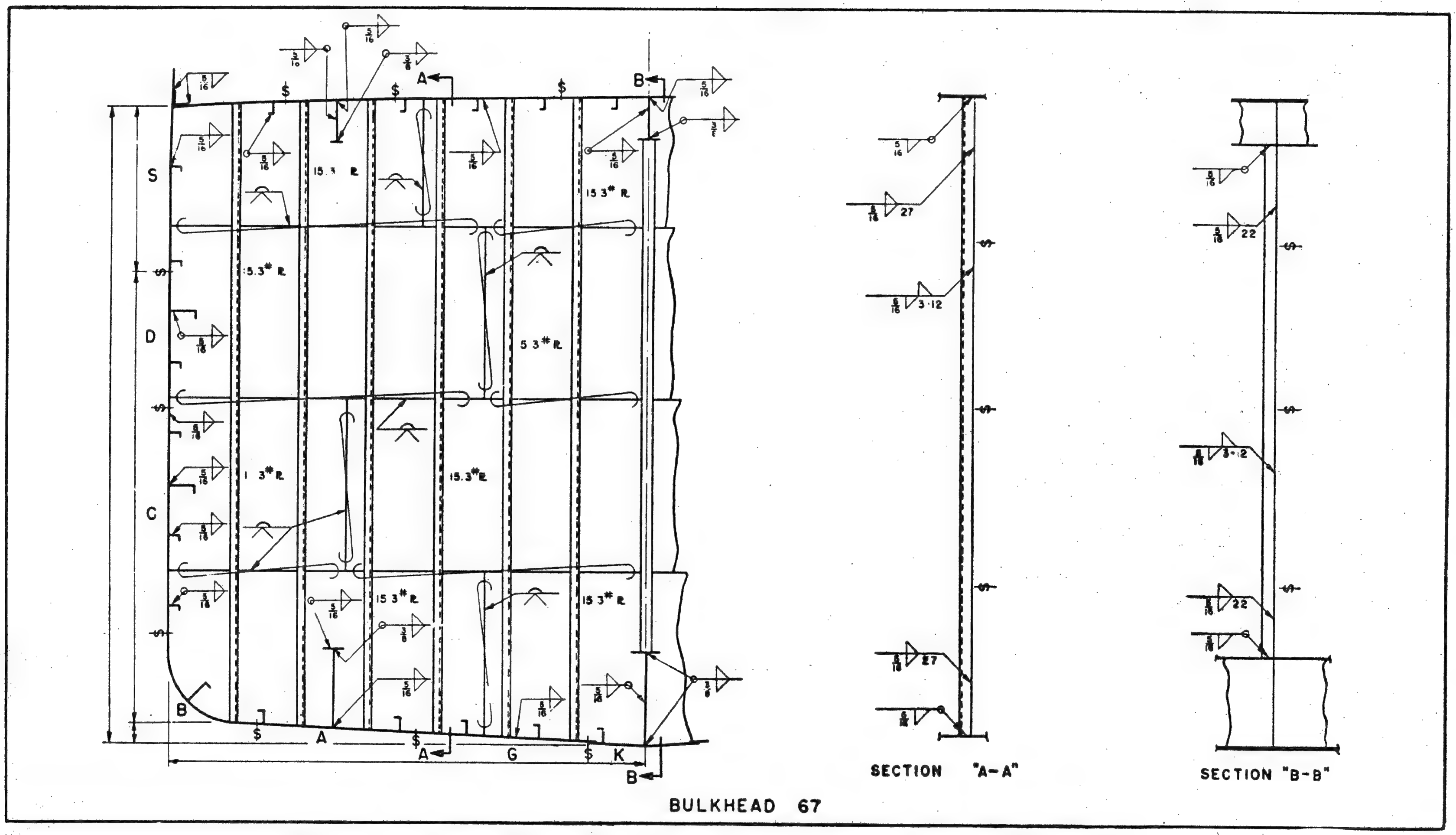


Fig. 44—Use of Arc Welding Symbols on Marine Drawing

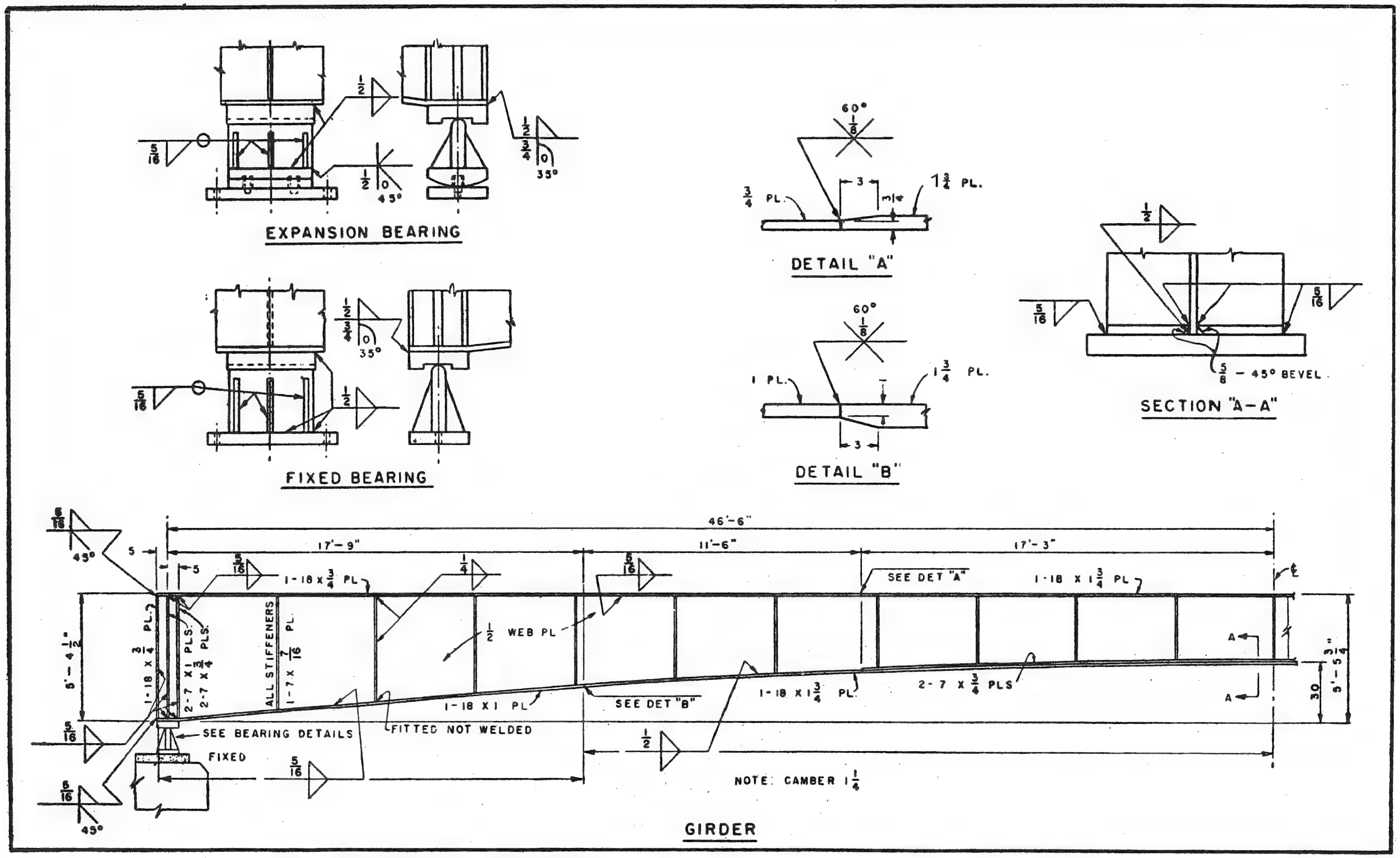
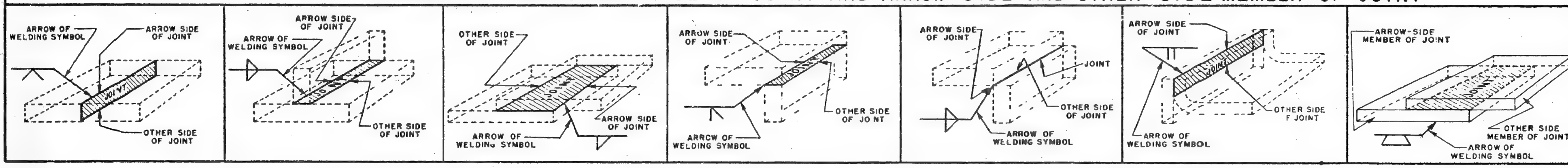


Fig. 45—Use of Welding Symbols on Structural Drawing

AMERICAN WELDING SOCIETY

SUMMARY OF STANDARD WELDING SYMBOLS

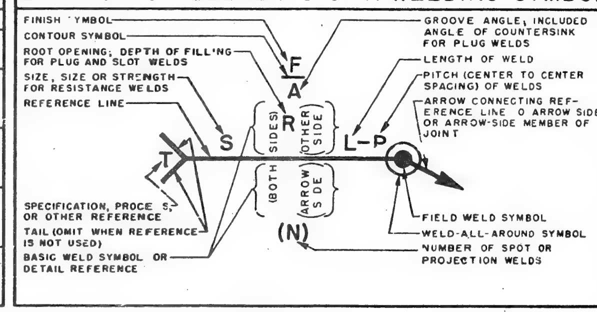
IDENTIFICATION OF *ARROW* SIDE AND *OTHER* SIDE OF JOINT AND *ARROW*-SIDE AND *OTHER*-SIDE *MEMBER* OF JOINT



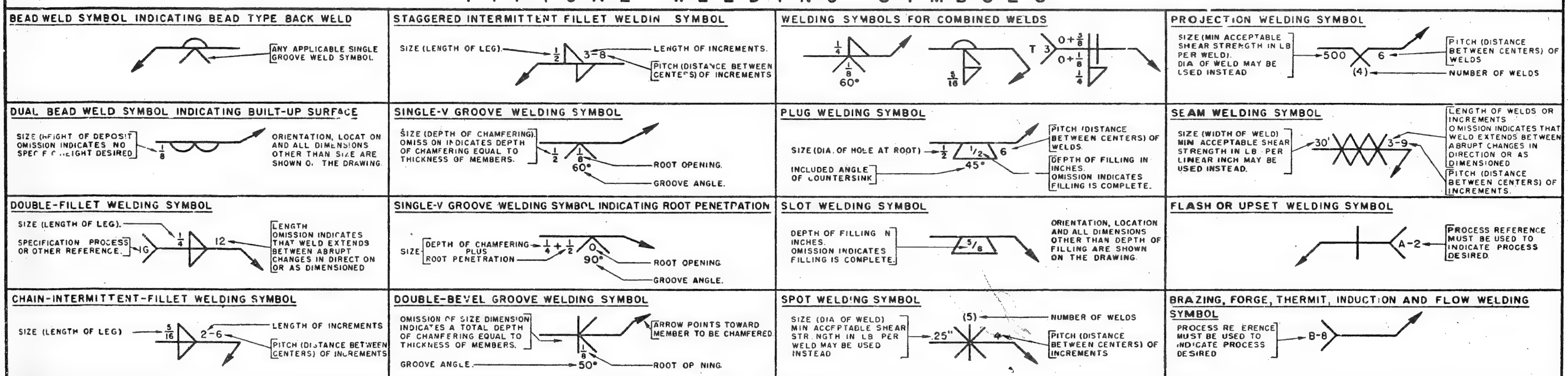
BASIC WELDING SYMBOLS

LOCATION SIGNIFICANCE	ARC AND GAS WELDING SYMBOLS								RESISTANCE WELDING SYMBOLS			
	BEAD	FILLET	PLUG OR SLOT	GROOVE: SQUARE	GROOVE: V	GROOVE: BEVEL	GROOVE: U	GROOVE: J	PROJECTION	SPOT	SEAM	FLASH OR UPSET
ARROW SIDE	GROOVE WELD SYMBOL									NOT USED	NOT USED	NOT USED
OTHER SIDE	GROOVE WELD SYMBOL									NOT USED	NOT USED	NOT USED
BOTH SIDES	NOT USED		NOT USED						NOT USED	NOT USED	NOT USED	NOT USED
NO ARROW-SIDE OR OTHER SIDE SIGNIFICANCE		NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED			

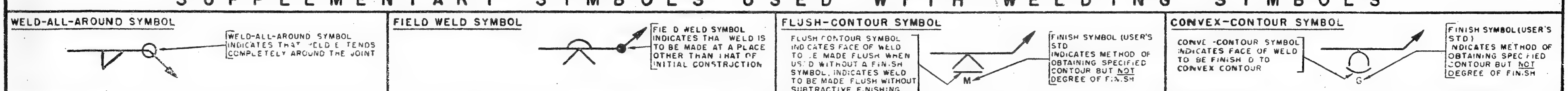
LOCATION OF ELEMENTS OF A WELDING SYMBOL



TYPICAL WELDING SYMBOLS



SUPPLEMENTARY SYMBOLS USED WITH WELDING SYMBOLS



LESSON 2 A

SUPPLEMENTARY BLUEPRINT READING*

Blueprint reading was treated in Lesson 2 in an elementary way as an introduction to welding symbols. This lesson is a more advanced study of the subject and being complete in itself it may be used without reference to Lesson 2.

Blueprints make use of a sign language, but one that is precise and exact. Like a sign language it is universal, understood equally well by all who have taken the trouble to study and learn, whether they be English, American, German or Japanese.

There are two parts to this sign language, the making of signs (the drawing) and the translation of the signs (blueprint reading). It is important that the draftsman makes use of the correct signs and uses them in the normal accepted manner. It is equally important that the men in the shop interpret these signs correctly. Thus blueprint reading is a necessity for the designer, draftsman and shop foreman.

It is equally desirable for the welding operator who, if unable to properly interpret a drawing and welding symbols, must constantly rely on his foreman or others with superior knowledge. He, himself, should be able to translate the drawing into a welded product. To do so is not only essential but a most satisfying accomplishment. It is hard for anyone to admit he is unable to properly read and understand a drawing. On the other hand, it may be dangerous and costly to proceed without fully comprehending the instructions as revealed by the blueprint. The only answer is to know.

It should not be supposed that reading this lesson or even a close study of it will make anyone fully proficient in the reading of drawings. Practice is necessary. For this reason several exercises throughout the period of the course will be based on this lesson and students are advised to work over actual shop prints whenever they can in the course of their work.

It has been implied that every operator should be able to read drawings. It might be gathered from this that he should know how to make a drawing, that is, be a draftsman. This isn't true any more than he should know how this page is printed

*From - "Simple Blueprint Reading" - courtesy of The Lincoln Electric Company.

in order to read it. Learning to be a draftsman is entirely different and is not being discussed here except insofar as it affects the reading of the drawing. To read the drawing much must be known about the draftsman's work, but it isn't necessary, for example, to know how to draw a certain type of line or make a certain figure, but it is necessary to know what that line or figure means. In other words, the letters, the words, the sentences, must be known so the story may be read. Knowing these, all that is necessary then is to practice or study reading for a sufficient length of time to become proficient in it, and in the interpretation and visualization of the story, i.e., part to be made.

It might be thought that as we learn our letters first and then the words, it would be well to learn the meaning of lines and then a drawing. However, it is easier to start from an object (such as a simple welded base, which has been fabricated) and work backwards to the lines. This gives something tangible and familiar with which to work.

As an example consider a simple welded base made of angle iron as the object of our discussion.

We find there are two general ways by which the object may be illustrated - one a picture drawing and the other a mechanical drawing.

Picture drawings may be divided into two general classes, true pictures called perspective drawings and distorted pictures called isometric - oblique and cabinet. Picture drawings are of use in studying the appearance of a part but are not of any great use for construction purposes because they are not to scale.

The familiar example of looking down a railroad track, the rails seeming to run together, illustrates the picture effect. The farther away a tie is the smaller it appears. We know the ties are all of about the same length but in the true picture they do not so appear. A picture of a simple welded base is shown in Fig. 2A. 1. Note that the lines on the paper do not give or represent the actual length but combine to form the picture.

Such a picture as shown in Fig. 2A. 1 is useful when studying appearance. It does not easily serve as a means of giving information and dimensions for the fabrication of parts into a completed assembly.

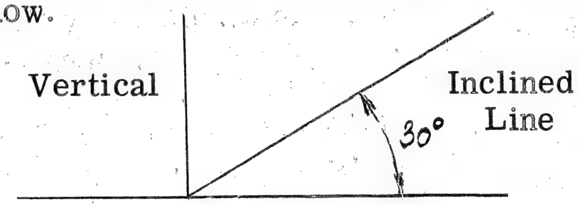
Another type of picture drawing different from the perspective in that it contains some information and data regard-

ing dimensions, is known as "Isometric". This is made similarly to the perspective but is not a true picture. The rear dimensions are too large and the object appears distorted. Isometrics are sometimes called "Shop perspectives."

Although isometrics and perspectives are alike in that they present a picture, some of the lines on the isometric are made to actual length or scale not shortened as they are in the perspective. Certain dimensions may then be easily scaled. These drawings are much easier to make than perspectives, give an idea of what the part looks like and may be used as drawings from which the part may be made.

In Fig. 2A. 2 is shown an isometric drawing of the simple welded base.

The difference between this and the perspective is evident by observation of these two drawings. In Fig. 2A. 2 the width, length, depth are laid off on inclined lines, usually 30° to the horizontal, and the points so located are connected by vertical lines. The result is an isometric drawing. These lines are drawn as shown below.



Referring to Fig. 2A. 2 consider the angle iron end nearer the reader. The length of each leg may be measured and the length of the angle as well. The length and width of the top of the base may be determined by measurements.

It is evident however, see Fig. 2A. 3, that the distance as measured on the drawing between diagonal corners AB is not the same as diagonal distance CD. Consequently the measurements of these dimensions do not tell the true story.

It is very necessary to have drawings from which all important dimensions may be obtained either by scale or direct measurement. That such a method of making a drawing may be developed, it is necessary that some study be made of how we observe things, how we know size, how that information as to size and shape may be recorded and transmitted to someone else and how he in turn may translate and visualize this information - so a complete idea as to the object is obtained. This is important. In order to build something it's necessary to know what it looks like.

Suppose a purchase is to be made, and the article is in a showcase. To obtain a complete picture of that article it is necessary to move from one position to another around the showcase. The three positions which will usually tell the buyer most about the article are - looking down from the top - in from the front and in from the side. Suppose the welded base is placed in a showcase and studied from the front, top and side. What kind of a picture would be obtained from each position ? Would any one view completely describe the base to the observer ?

In Fig. 2A. 4 the showcase is pictured as it would look at a rather short distance.

Inside the showcase is the welded base - resting upon blocks which elevate it for inspection. The sides of the base are parallel to the sides of the showcase and the top parallel to the top of the showcase.

If the glass of this case is marked with a special pencil (these are available), it would be possible to mark on the glass the points and lines representing edges and surfaces of the base. These marks would be placed on the glass where an imaginary line, at right angles to the glass, and extended from the edge or surface being drawn, meets the glass side of the showcase. Carefully note that the eye moves to a new position for each point. The "line of sight" from the eye to the point being drawn is always at right angles to the sides of showcase. Three views result, (shown in Fig. 2A. 5) - Top, Front, Right side.

These views are called projected views. When the limitation that every "line of sight" be at right angles to the showcase side was set, the process became a "right angled projection of points". The word "orthographic", a Greek word meaning "right angled writing", is sometimes used to describe this method of drawing. The drawing is called "orthographic projection".

A study of Fig. 2A. 5 indicates that any single view, by itself, does not completely describe the base. By considering all three views together and interpreting the relation of one line in one view to another in another view, the true picture is formed. This is not difficult. It can be clearly shown by further discussion of the showcase.

For example, when an edge is seen as a line in the front view, it must appear as a line or a point in the other views. Check this by observing the form in which each edge and surface of the base appears in each of the three projected views of Fig. 2A. 5, and compare your conclusions with your mental

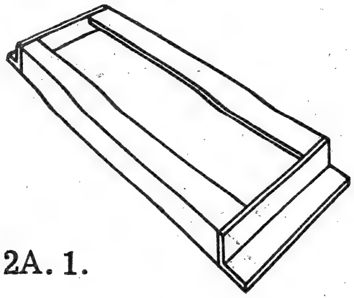


Fig. 2A. 1.

Perspective or Picture Drawing of a Simple Welded Base.

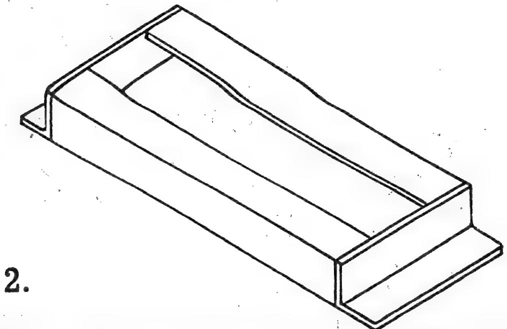


Fig. 2A. 2.

Isometric or Dimensioned Picture Drawing of a Simple Welded Base.

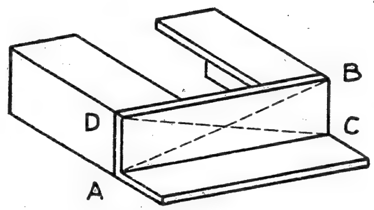


Fig. 2A. 3.

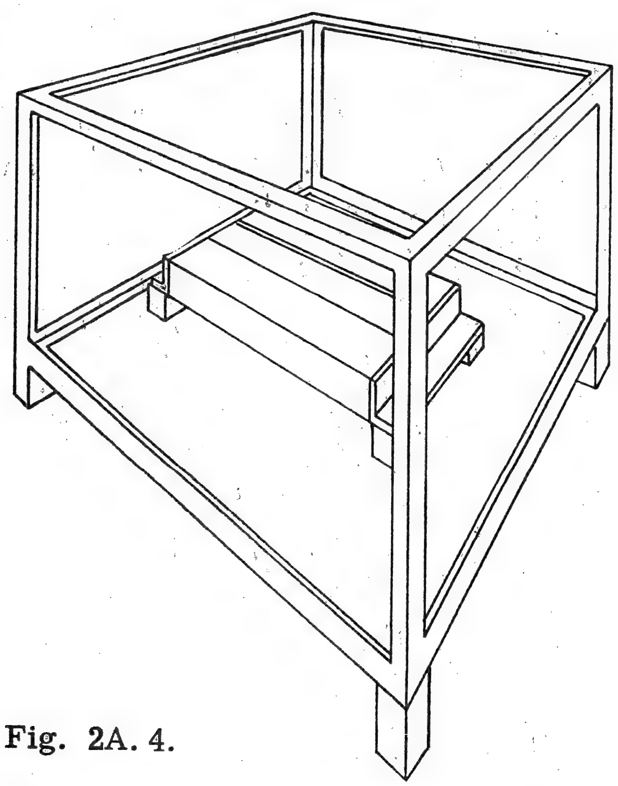


Fig. 2A. 4.

Welded base in a Showcase as it would appear observed at a rather short distance from the showcase.

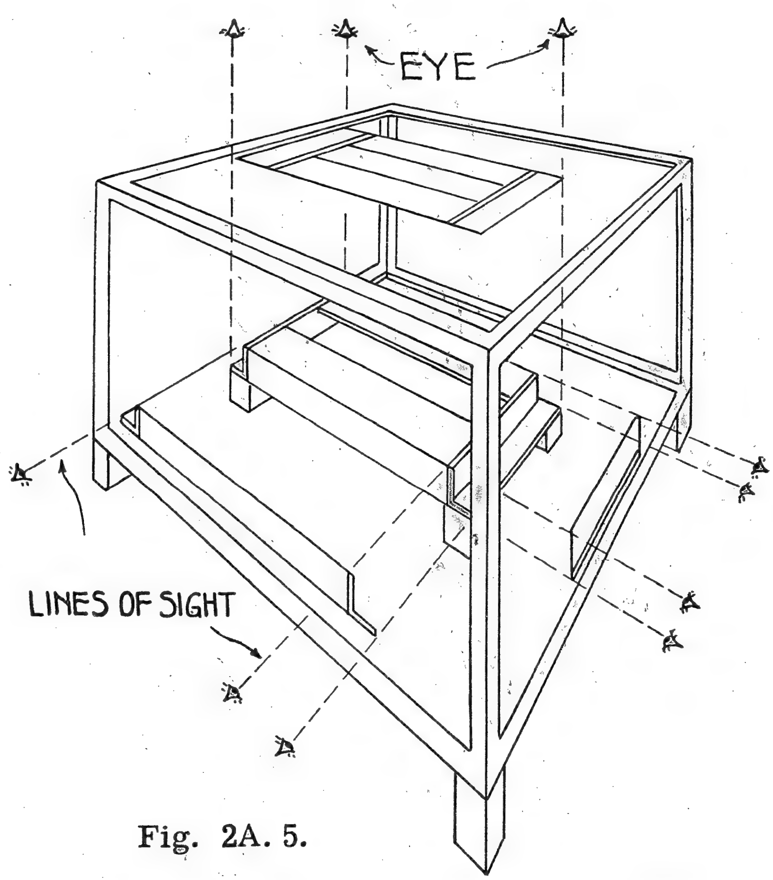


Fig. 2A. 5.

Line of sight. Projection of views to the sides of showcase.

picture of the top, front and right side of the base in a showcase. Continue this study until you are sure that this idea of the form in which an edge appears in the three projected views is thoroughly understood. It is essential to reading blueprints.

Since the drawing must be made on a sheet of paper, the three views must be shown together in some way that will bring out the fact they are really projected at right angles to each other. How is this to be done on a flat sheet of paper ? Suppose the transparent sides and top of the showcase were hinged on the edge nearest the front, and, after the projected views were drawn on the sides of the showcase, the hinged top and right side were swung around until they were both in the same plane as the front of the showcase. Fig. 2A. 6 is a picture drawing of this operation before the top and right side are in the final position.

Is the change from a three dimensional box to a sheet of paper very difficult ? Every time a drawing is read, this conception of swinging out the top and right side views must be remembered and applied. The next step is to draw the three views as they would appear when the top and side are swung so as to line up with the front of the showcase. Fig. 2A. 7 is the front of the showcase with the top and right sides swung around to position.

Notice that vertical and horizontal lines would connect the edges in the front view with the corresponding views of those edges in the top and right side views respectively. Is it apparent that folding back the top and right side pieces forms the outlined showcase ?

After studying Fig. 2A. 7, it is seen that the showcase outline can be discarded and the three views drawn without the showcase, although the original operation involved must not be forgotten. Fig. 2A. 8 shows the three views with no showcase outline. The same projection rules hold, for vertical and horizontal lines will connect the same edges in all three views.

Going into this a bit more in detail, a few examples and illustrations of projections of a very simple nature will serve to emphasize the method.

Using a point, then a line as the object to be drawn, simple illustrations are given in Figs. 2A. 9 to 2A. 11 inclusive.

In Fig. 2A. 9 a point has been pictured in the center of a glass cube which is a simple substitute for the showcase.

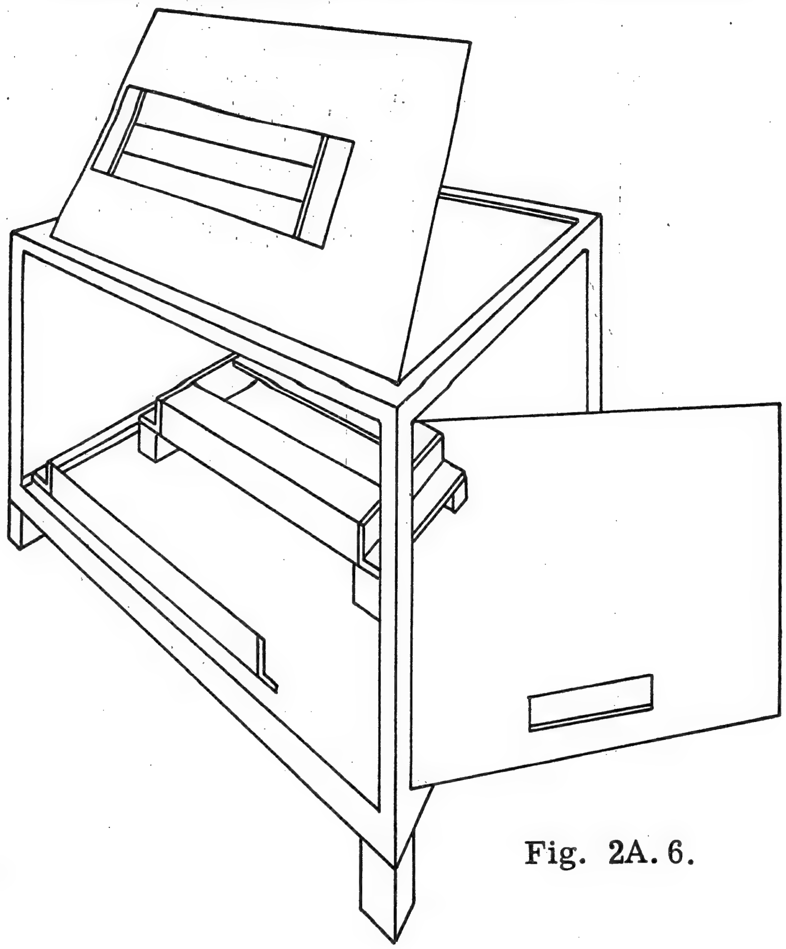


Fig. 2A. 6.

The hinged showcase side and top being swung into plane of the front.

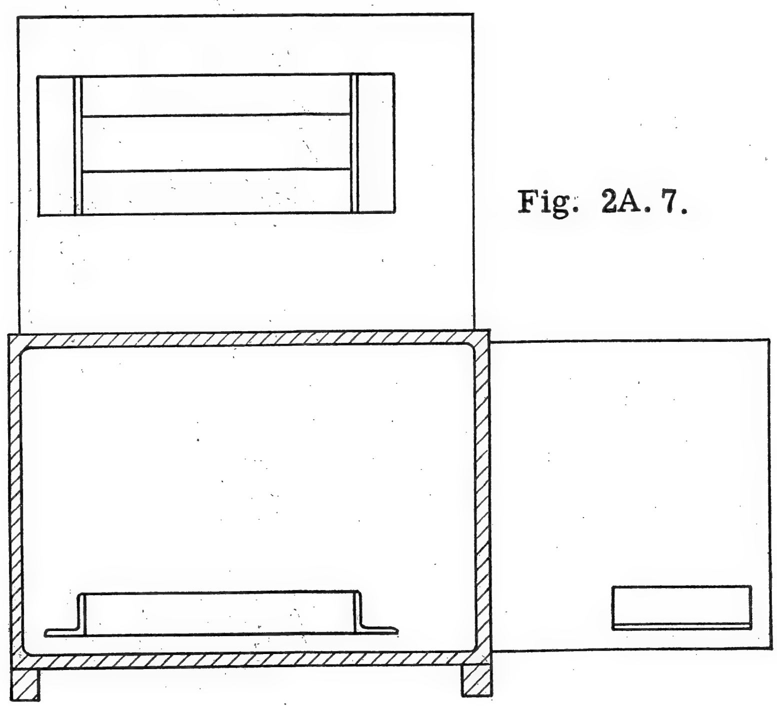


Fig. 2A. 7.

The front of the showcase with the hinged top and right sides swung into the same plane. Note the relationship of the three views drawn on the sides of the showcase.

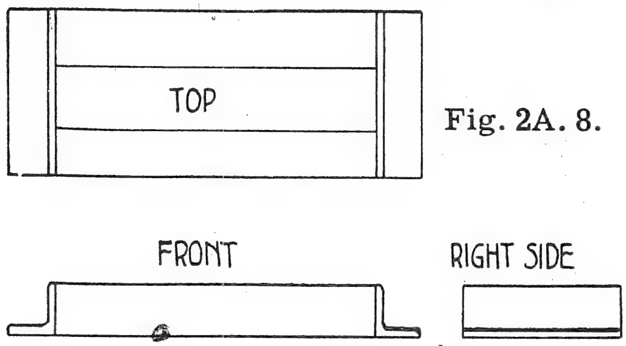


Fig. 2A. 8.

The three projected views of Fig. 2A. 7 without the showcase outline. They are moved closer together and the general relationship is indicated.

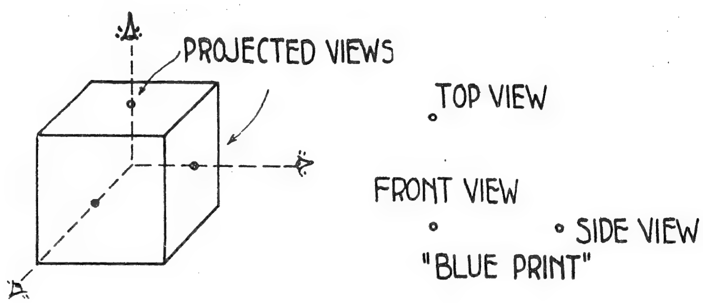


Fig. 2A. 9. A point in center of a cube observed from 3 sides of a cube.

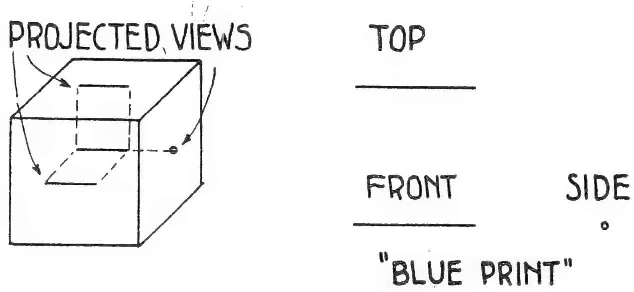


Fig. 2A. 10. Three views show the line to be at right angles to the showcase side and parallel to the front and top.

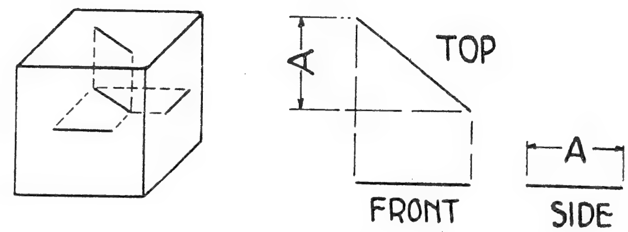


Fig. 2A. 11. The 3 showcase views show the line to be horizontal but the left end is farther from the eye than the right end by the distance marked "A".

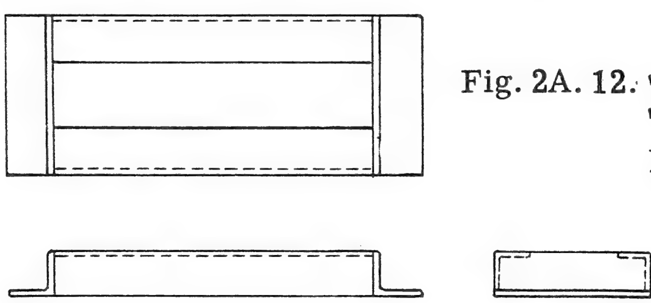


Fig. 2A. 12. "Showcase" Drawing with "Dotted" lines showing hidden edges of surfaces.

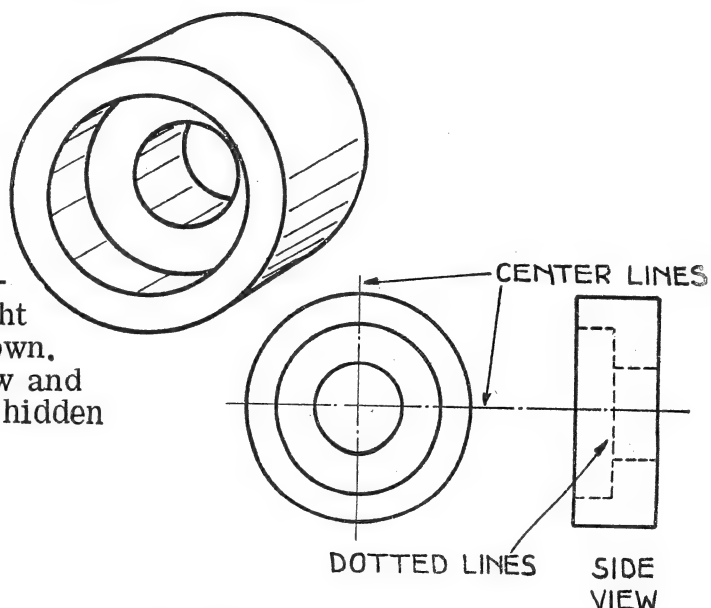


Fig. 2A. 13.
Top:- Picture drawing of counterbored collar. Bottom:- Mechanical drawing of counterbored collar. Front and right side "showcase" views are shown. Top view is same as side view and is not shown. Dotted lines show hidden edges and surfaces.

No matter where the observer stands to look at it, the picture is just a point.

Remember the principle that each line of sight between the eye and the object is at right angles to the sides of the cube (or showcase). The line in Fig. 2A. 10 appears as a line from the front and top and as a point from the side since the line referred to is at right angles to the sides and parallel to the front and top.

Examination of Fig. 2A. 11, shows a line which is in a horizontal plane, but the left end is farther from the observer than the right. Notice that it appears as a line in all three views.

Keeping these facts in mind refer again to Figs. 2A. 7 and 2A. 8. From these a picture of the base as you would see that same base in your daily work may be readily formed.

This visualization or forming the picture of the object is very important. It is the "reading of the blueprint".

LINES AND THEIR USES

The fact, when known, that the base is fabricated of angle iron, imparts information about the inner surfaces which would otherwise be lost, if only the views as drawn in Fig. 2A. 8 were given. What about pieces having surfaces, edges and corners which cannot be seen when a piece is observed in a showcase ? There is need for a method of giving information about both visible and hidden outlines, surfaces, edges and corners. The "dotted" line is used to indicate "hidden" outline; the "solid" line being used in indicating "visible" outline.

_ _ _ _ _ _ _ _ _ hidden outline

____________________ visible outline

Knowing that the base is fabricated of angle iron, how would the hidden surfaces appear in a drawing similar to Fig. 2A. 8 ?

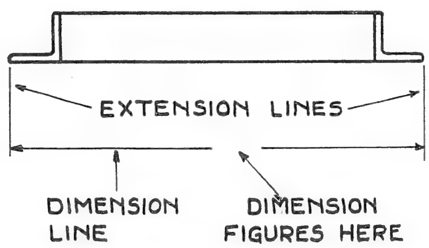
Fig. 2A. 12 gives the answer. It shows the complete story of the outline of the base - hidden and visible - inside and outside.

Further thought on the subject of imparting complete information in "showcase" views reveals the need for other distinctive lines to communicate important details to the reader. Some objects are symmetrical about a center line or plane, (one half of the piece is exactly the same as the other half) so the center line was added to the list.

The center line is always used in indicating the center of holes and cylinders for the center is most important in drilling a hole or turning a shaft. Fig. 2A.13 shows both "dotted" and "center" lines used on the drawing of a thick washerlike piece which has been drilled through to form a hole of one diameter - then the hole bored to a larger diameter for a part of the thickness.

Not only the shape, both external and internal, is essential but it is necessary that all fabricating dimensions be detailed so they may be easily and accurately read. The dimension line is used for this and will be discussed in more detail later.

The lines on which the dimension arrow heads end are called "extension lines" and are used to indicate the end of the dimension and keep the dimension lines off the drawing itself.



Details of the inner construction may be classified by showing how the object would appear if cut in two. A drawing may be made of the view which would result if this were done. The "cutting plane" line is used to indicate just where the cut is made. (Fig. 2A.14).

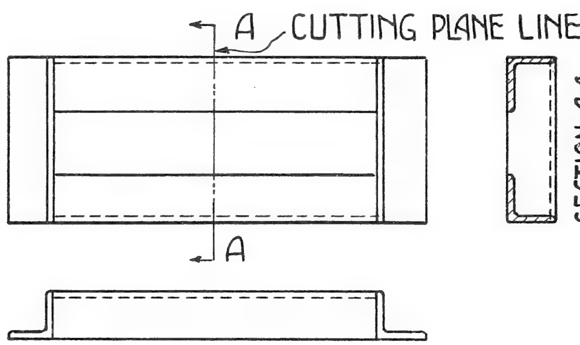


Fig. 2A.14.

Since some objects are the same throughout their length it is not necessary to make a complete drawing. The drawing is shortened by omitting part of the uniform section. This is indicated by a "break" line, which is usually wavy or jagged but in some cases, as the "broken" shaft, a pictorial outline.

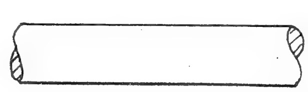


Fig. 2A. 15 illustrates this applied to the sides of the base shown in Fig. 2A. 8.

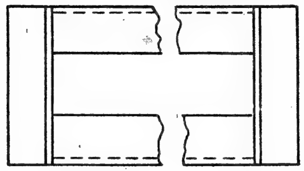


Fig. 2A. 15.

Finally there are Cross-hatching lines which will be dealt with later.

These lines form the "alphabet of lines". They show the relative location of intersecting surfaces and other information about the part drawn.

The following list should be learned:

Visible outline	Heavy solid line to indicate edge
Hidden edge or outline	Light, short dashes
Dimension line	Thin, solid line and arrows
Extension line	Thin solid line
Center line	Thin, long and short dash
Dimension line with reference or extension lines	Light lines indicating limits of dimension
Section or cutting plane line	Long and short dashes
Cross-hatching lines	or Thin, sloping lines
Broken section line	Full line with freehand breaks

The preceding pages indicate the basic methods for reading blueprints. These were illustrated by:

First: - An object represented by three views as when viewed from the front - right side - and top of a showcase. All points have been projected at right angles to the showcase glass. Second: - The "Alphabet of Lines" which conveys information about the object being represented by these three views.

READING THE DRAWING

To illustrate these points and develop skill in reading drawings, study each of the following drawings carefully and determine how the three "showcase" views combine to form a picture of the object.

Trace each edge from view to view, find out what each line indicates. Make a perspective or isometric sketch, then compare it with the corresponding sketch given after the drawings.

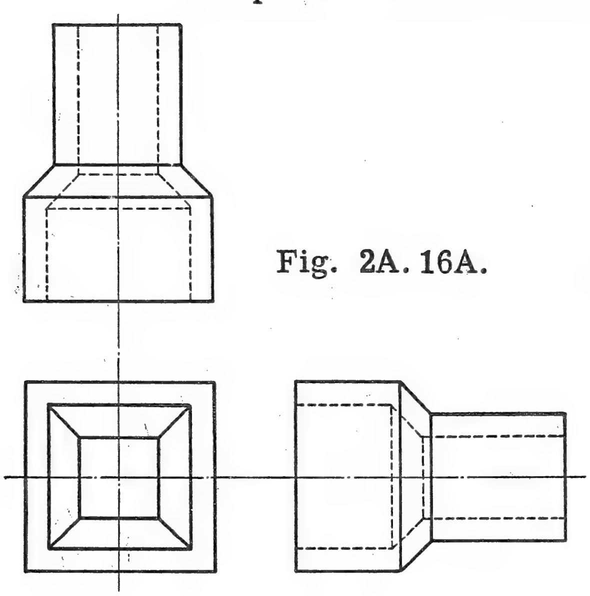


Fig. 2A.16A.

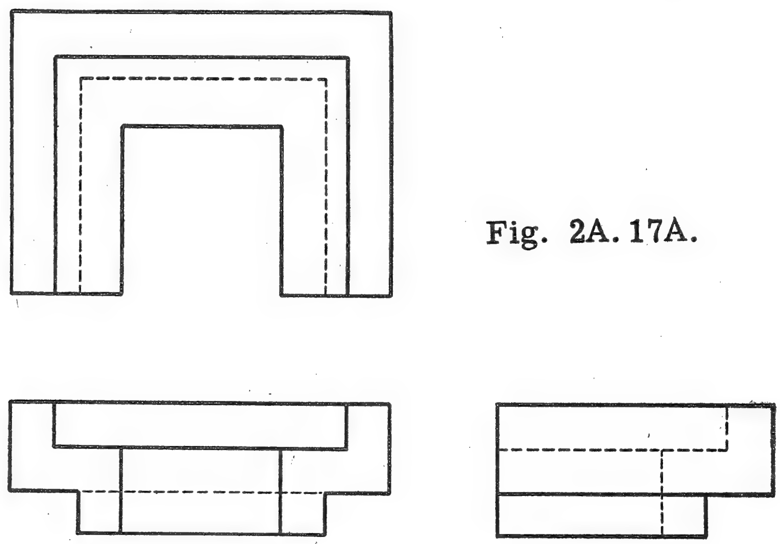


Fig. 2A.17A.

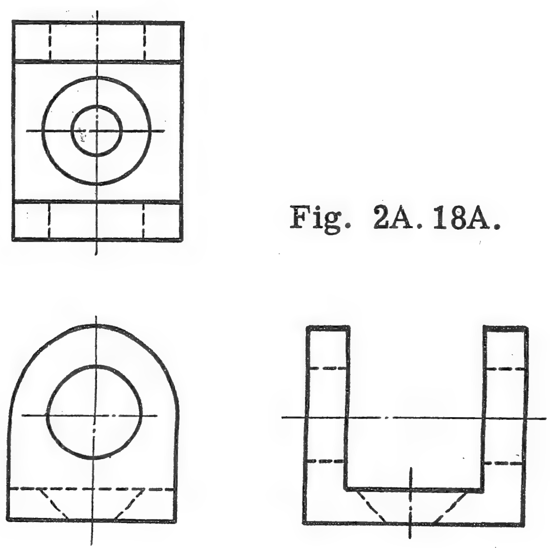


Fig. 2A.18A.

Following are the sketches, which have the same numbers as the corresponding drawings. Check your sketches with these.

Fig. 2A. 16B is a socket insert for a socket wrench. In the showcase views, dotted lines convey information more plainly than does the picture drawing. The reduction of outside to inside dimension is very easily measured as is the angle of bevel from the larger to the smaller dimension.

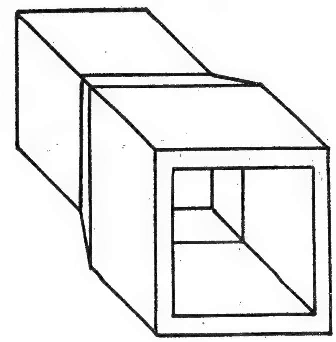


Fig. 2A. 16B.

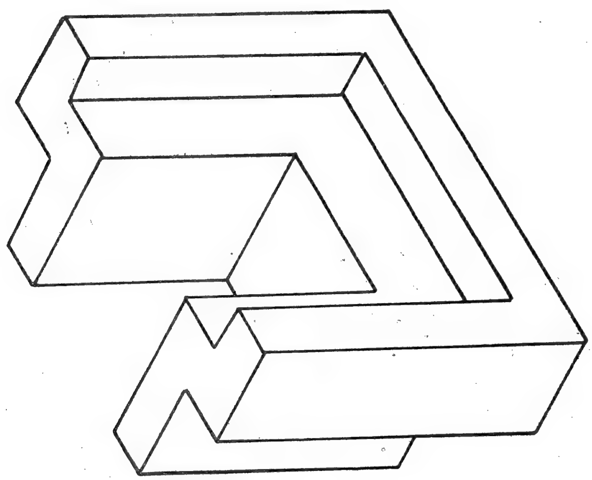


Fig. 2A. 17B.

Fig. 2A. 17B is a special bracket. Furnishes fine practice in reading surfaces of different elevation.

Fig. 2A. 18B is a simple bracket. The angle of countersinking the base hole is readily determined from the "dotted" or hidden outline. It would be very difficult to determine this angle from the picture or perspective drawing.

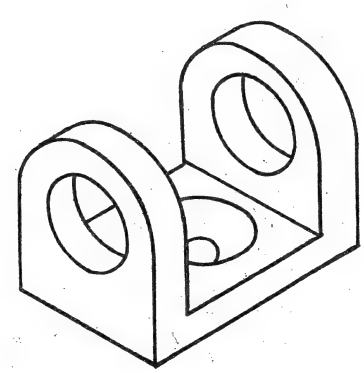


Fig. 2A. 18B.

Continuing this discussion along these same lines, a number of other parts are shown in both types of drawings. Compare these as you did the preceding ones. Do this very completely. Just a mere reading of the text will not result in a knowledge of blueprint reading. The text must be studied.

Fig. 2A. 19A is a blueprint of a clamp plate with interesting elevation detail. Study these views and compare your ideas obtained with Fig. 2A. 19B - a pictorial drawing of the same clamp plate.

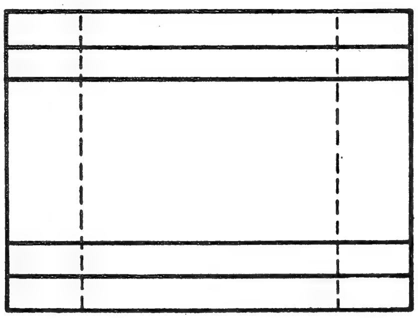
In Figs. 2A. 20A and B, the picture drawing more or less shows that the central hole is countersunk, but the use of "dotted" lines to show hidden outline clearly interprets this in the top and right side views of the "showcase" drawing. You can see that the "dash-dot" center lines locate the distance between centers of the holes, particularly in the front view, which is necessary information for the machinist.

Figs. 2A. 21A and B represent a very oddly formed bracket which requires very careful inspection of its three showcase views to obtain the correct picture.

Figs. 2A. 22A and B give a very good example of how information regarding machining can be shown. The left side view was used to bring out the details of that side as visible outline instead of invisible outline.

This shows it may be necessary to include a left side and sometimes a bottom and a rear view to fully explain the object.

Figs. 2A. 23A and B show a support bearing which was better represented by both right and left side views. This is clearly evident by inspection of Fig. 2A. 23B. Fig. 2A. 23B is a picture of the desired part - while Fig. 2A. 23A is the drawing to convey this information. This is an excellent example of how clearly information may be given. The choice of views is a problem for the draftsman who must present his subject in the clearest manner possible. As may be seen, the left side view appears to the left of the front view.



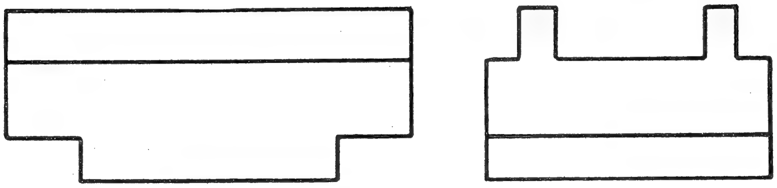


Fig. 2A. 19A.
Clamp Plate.

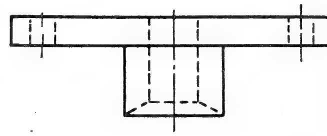
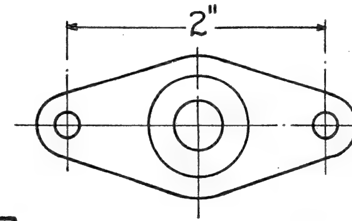
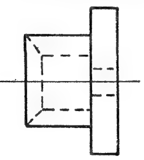


Fig. 2A. 20A.
Packing Gland.

SCALE DRAWING





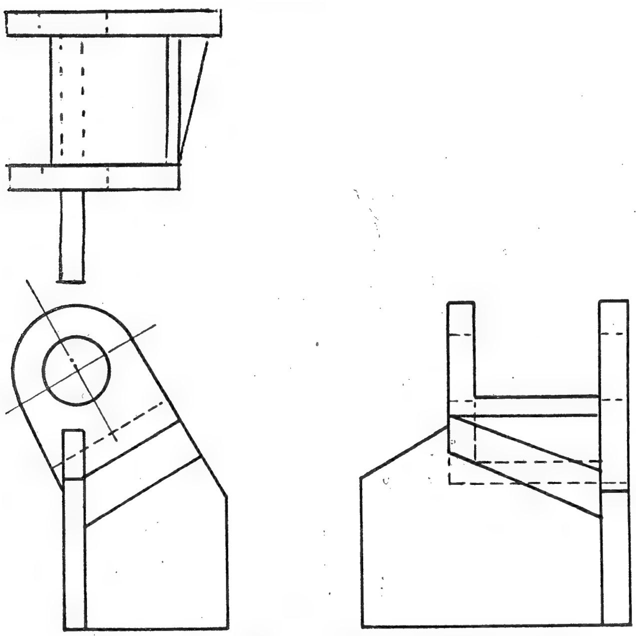
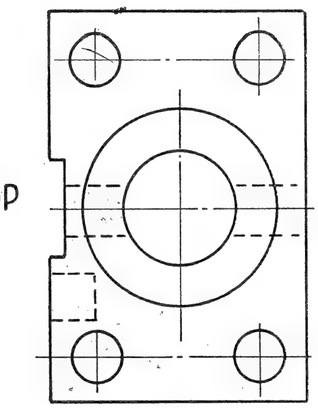


Fig. 2A. 21A. Angled Bracket.

TOP



LEFT SIDE

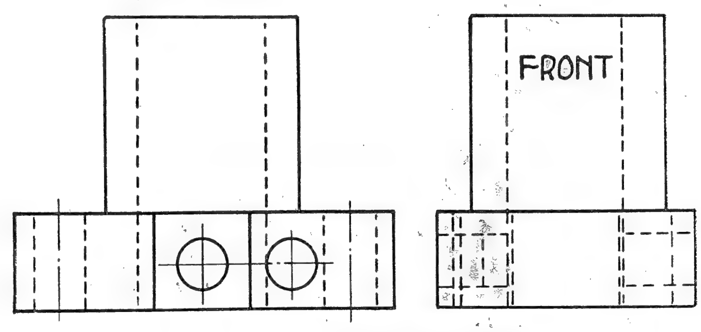


Fig. 2A. 22A.

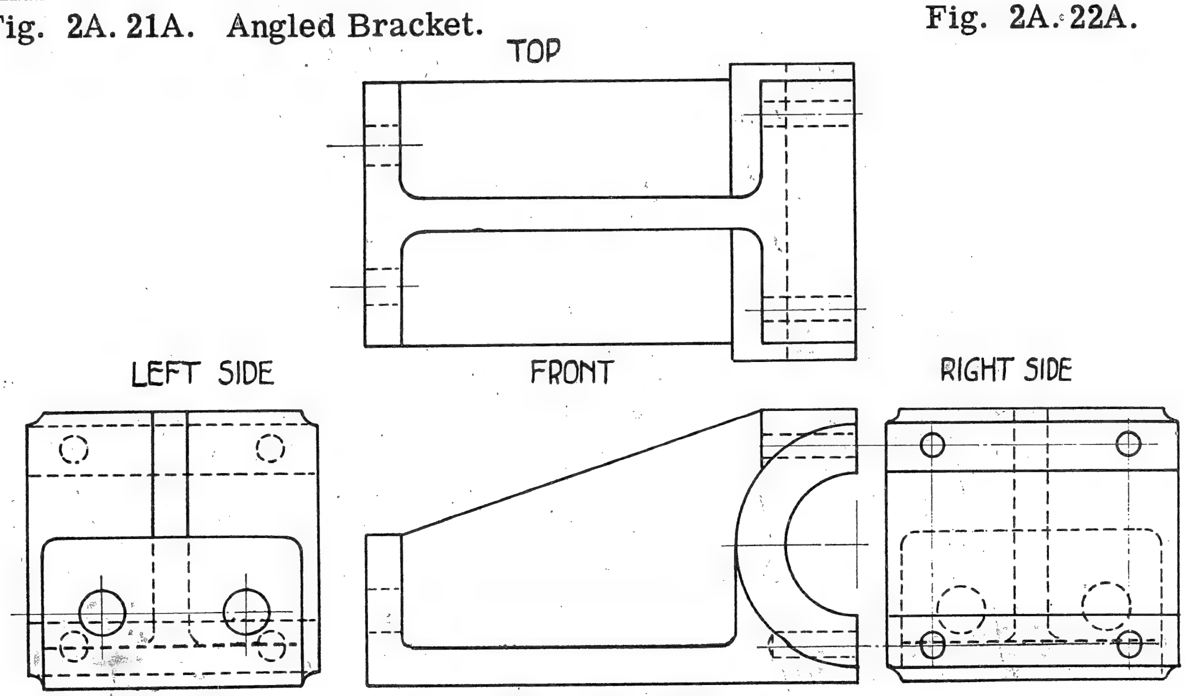


Fig. 2A. 23A.

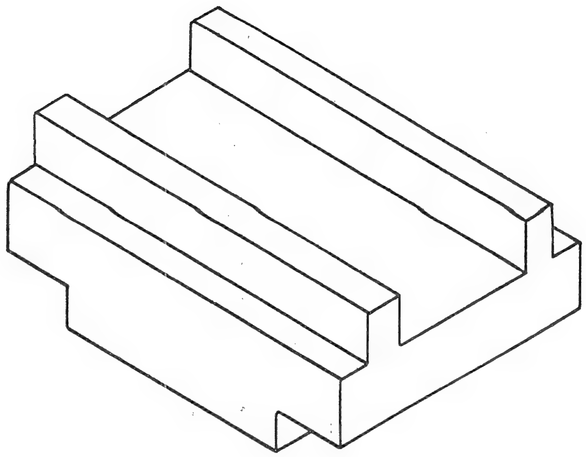


Fig. 2A. 19B. Clamp Plate.

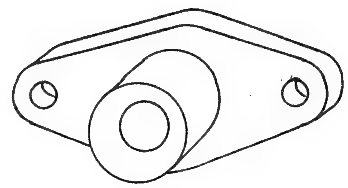


Fig. 2A. 20B. Packing Gland.

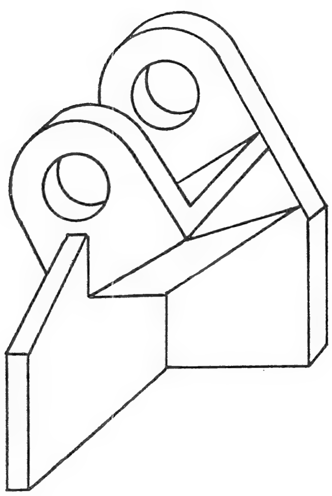


Fig. 2A. 21B.

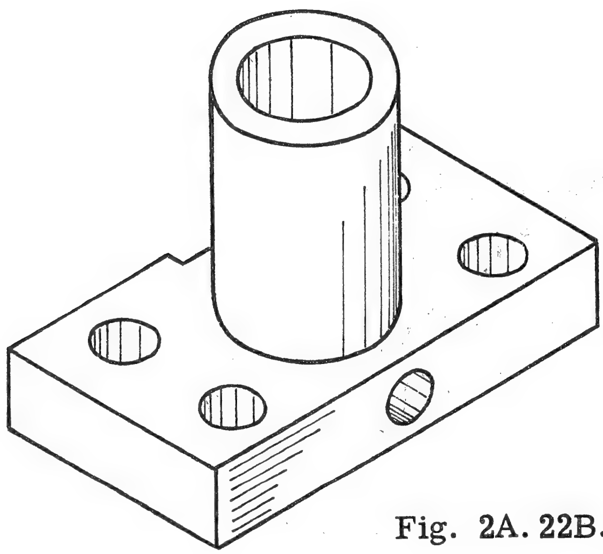


Fig. 2A. 22B.

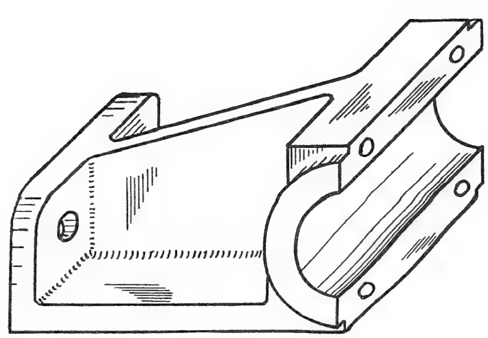


Fig. 2A. 23B.

Should a bottom view appear it will be below the front view, just as though we were viewing the object in a showcase and moving from the front for each view.

DIMENSIONING

Lines have been discussed with reference to visible and hidden outline and center-lines. Dimension lines were indicated. While dimensions can be measured on the drawings they may be and probably are, inaccurate due to various mechanical difficulties - such as paper shrinkage due to atmospheric conditions, etc.

For accurate work the dimensions must be given in figures on the drawing.

The dimension line was included in the alphabet of lines shown before. (See pages 2A. 10 and 2A. 11). The arrowhead is characteristic of the dimension line and indicates the limits of the dimension. Termination of the arrow head is either on an outline line, a center line, or an extension line. The extension line is lighter than the outline and is used only for dimensioning, usually being the continuation, after a short break, of the outline. Various methods of including the dimension numbers are used as shown in Fig. 2A. 24. The letter R following a dimension number means "radius". D means "diameter".

Dimension lines are generally placed so that the drawing may be read from the bottom and the right hand edge of the sheet.

Fig. 2A. 25 is the familiar welded base, this time dimensioned.

ALL NECESSARY dimensions should be given. The reader should not be required to make any calculations.

Where a dimension must be within certain limits they are given as for example

$$2.000 \begin{array}{l} + .000 \\ - .002 \end{array}$$

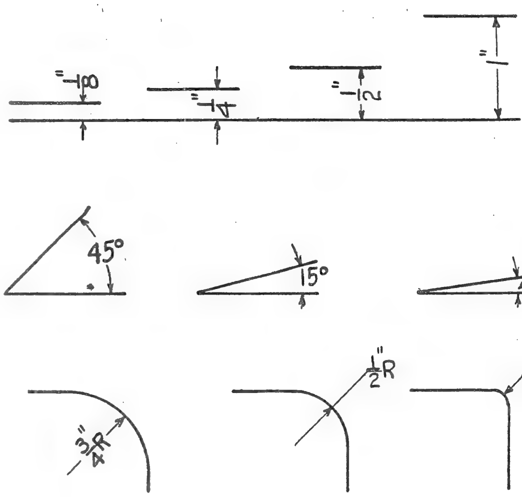


Fig. 2A. 24.

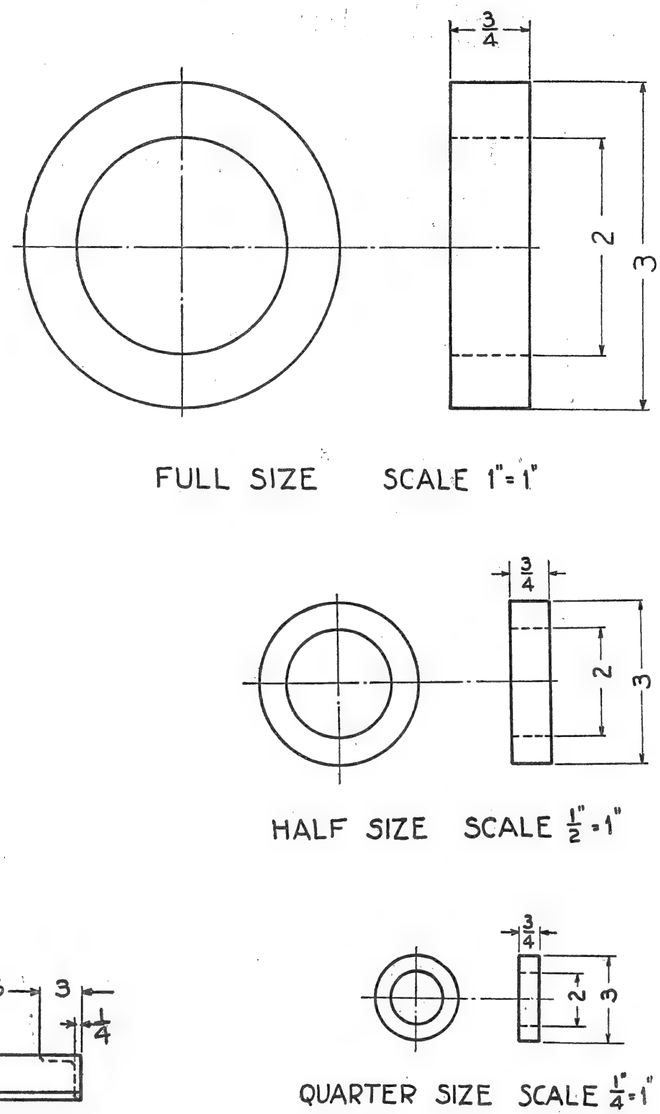


Fig. 2A. 27.

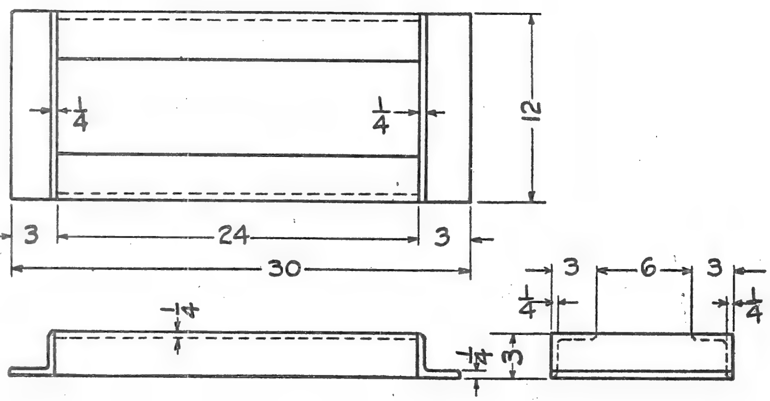


Fig. 2A. 25.

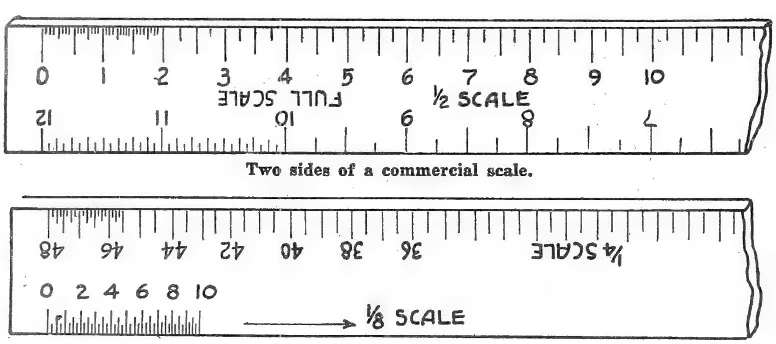


Fig. 2A. 26.

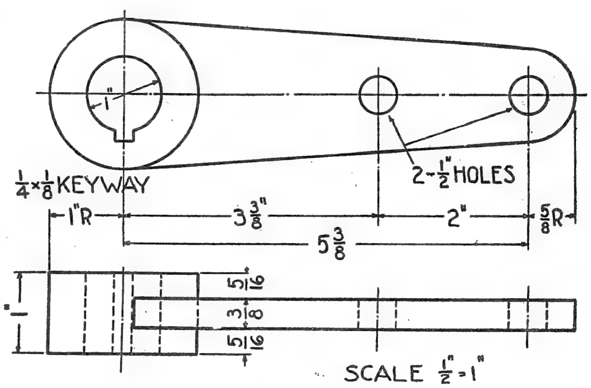


Fig. 2A. 28.

SCALE

In connection with dimensions the question of the actual size of the drawing arises. It is obviously impossible to make a drawing full size in all cases. For that reason drawings are made to proportion, that is - to a definite "scale". Models of airplanes are examples of reproduction to a reduced "scale" and that idea of cutting down every part to a convenient model size is just what is done in reduced scale drawings. Drawings may be "full size", 1/2 size, 1/4 size or any convenient size ratio. Usually a note is made on the drawing indicating the "scale".

Reduction		Note
Full size	Scale	1" = 1" or no note
1/2		1/2" = 1"
1/4		1/4" = 1"
1/8		1/8" = 1"

Also other scales such as 1" = 1'; 1" = 3'; 1" = 10'.

(See Figs. 2A. 27 and 2A. 28).

For conveniently measuring distances to these and other common scales you may obtain metal and wood rulers or "scales" which are marked in divisions of inches and feet to the scales indicated near the numbers. Fig. 2A. 26 shows a sketch of a scale which has four different reduction ratios. Should you want to mark or check a dimension on a 1/2 size drawing lay the edge marked 1/2 scale on that dimension and mark or read the size as you would an ordinary ruler. The 1/4 and 1/8 size scales are used in the same manner with no delay to multiply actual measurement in inches by the reduction number.

VIEWS

Every drawing should show a sufficient number and the proper kinds of views so that a clear idea of the object will be given. The number and kind vary with the object drawn. In some cases auxiliary and (or) broken views are used.

Some objects have a top or a side which is not at right angles to the front and it becomes more difficult to read the exact picture from the views as projected heretofore - especially when these slanting parts (which may be just a small slanting part of a large machine) have curved edges and surfaces.

Examine the pictorial drawing of an angle brace in Fig. 2A. 29.

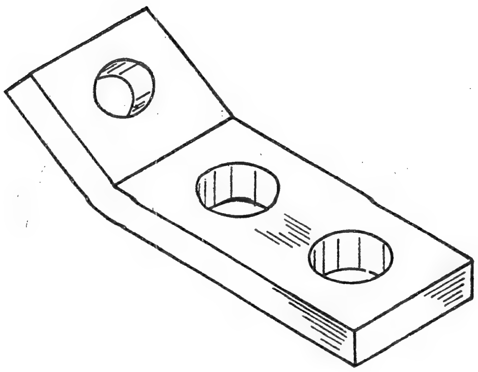


Fig. 2A. 29.

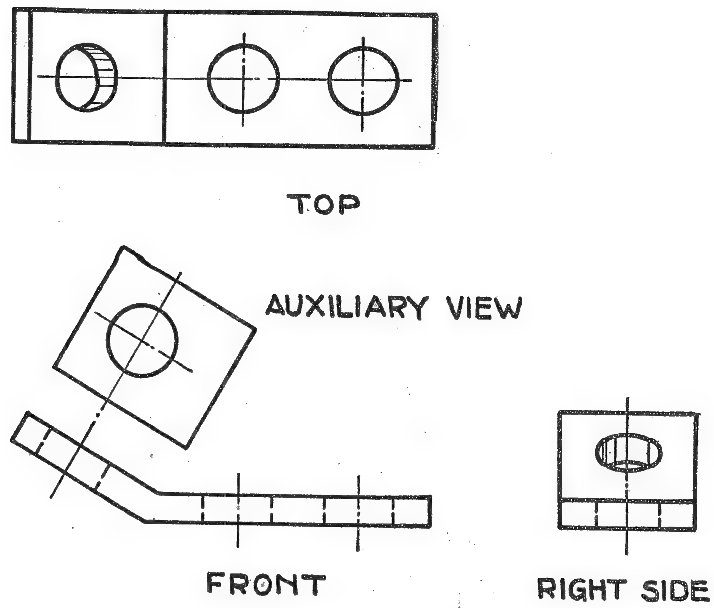


Fig. 2A. 31.

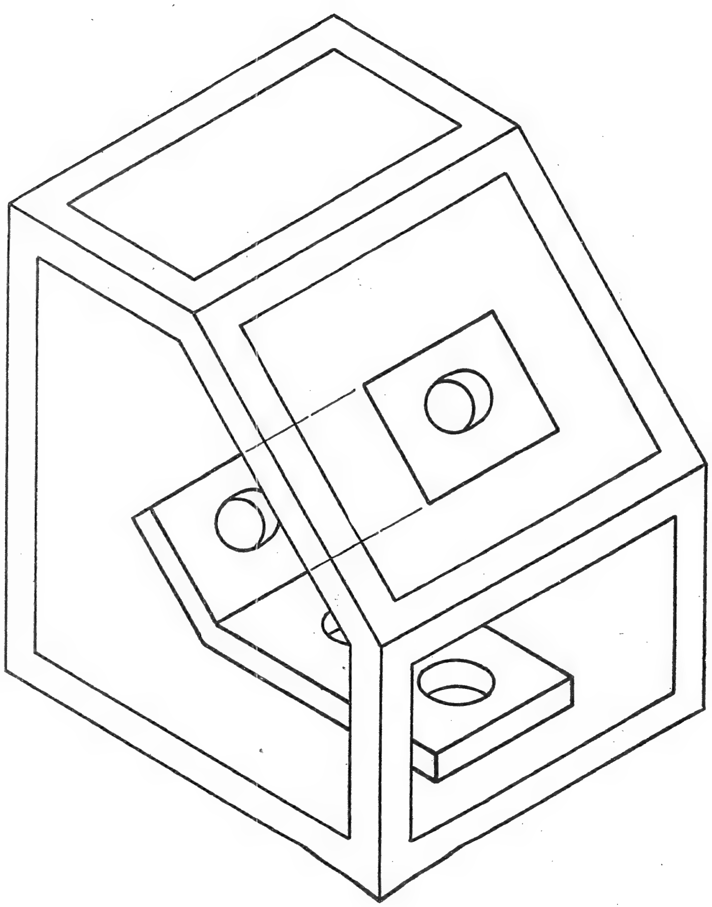


Fig. 2A. 30.

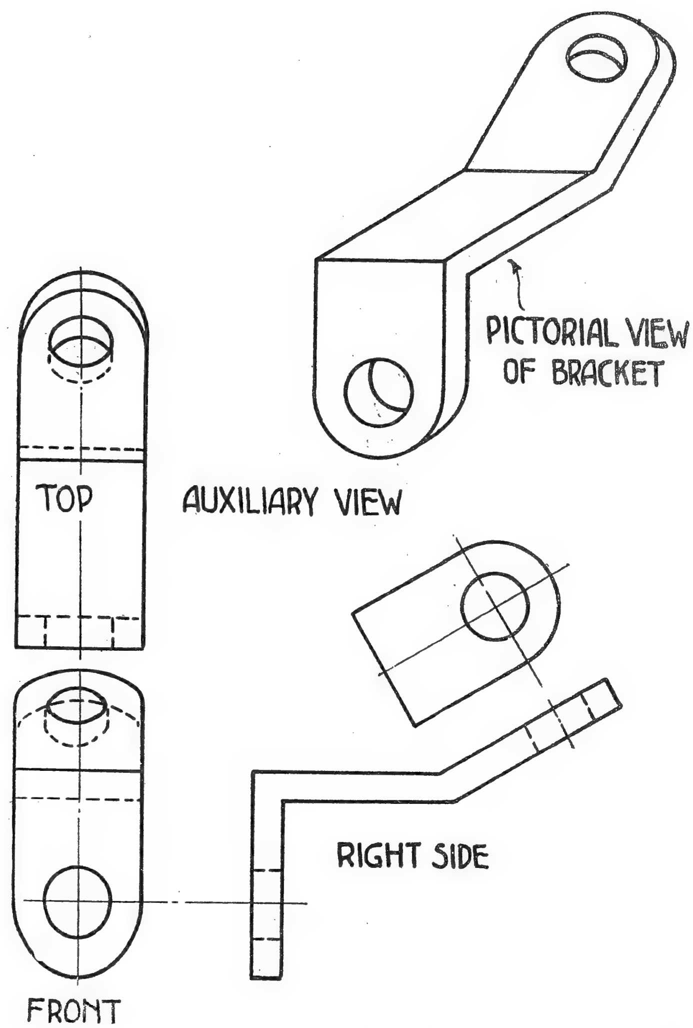


Fig. 2A. 32.

Upon placing it in the showcase for observation by the outlined method it is found that the three customary views do not show definitely that the hole is circular. What particular angle of vision would show this ? At right angles to the slanting surface of course ! A view, projected at right angles to this surface, may be obtained very simply.

One side or part of a side of the showcase can be inclined at the same angle as the slanting surface and the "line of sight" procedure used as before.

Fig. 2A. 30 is a pictorial drawing of the showcase with part of the right side slanted at the same angle as the brace.

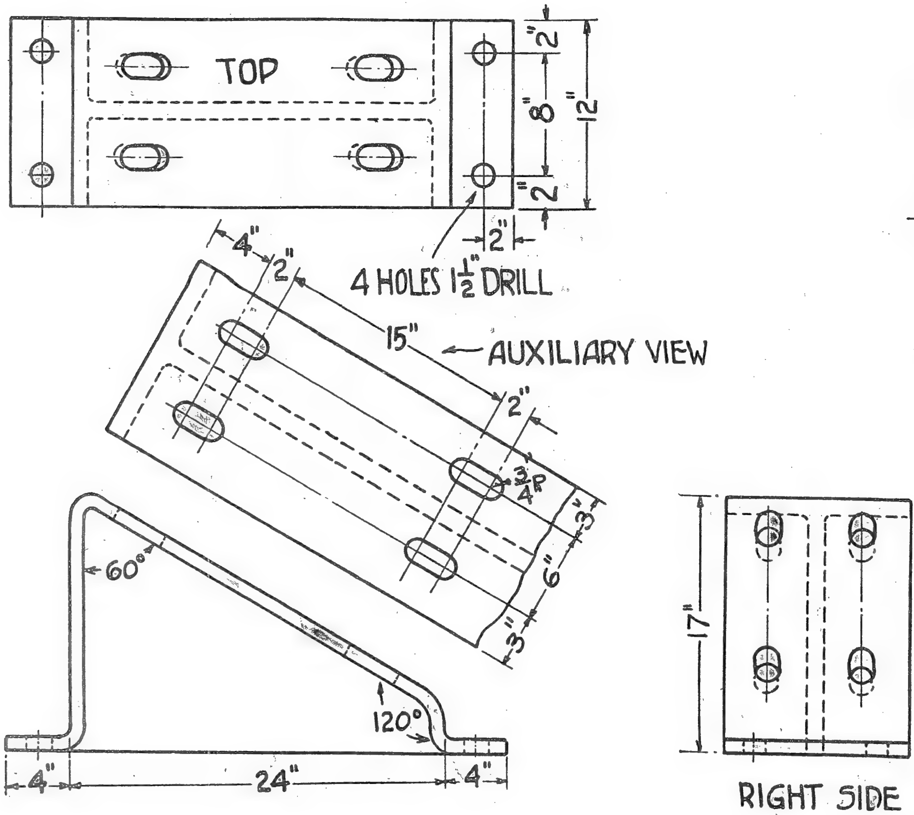
Inside is the angle brace and dotted lines at right angles to the slanting side connect corners of the brace to corresponding corners of the projected view.

Fig. 2A. 31 shows this view as it would appear in a blueprint. Definite proof that the hole is circular is contained in this "explanatory" or "auxiliary" view. Including more than just the slanting part in an "auxiliary" view makes the drawing harder to read so usually the view is cut or "broken", just the required part showing in detail.

Fig. 2A. 32 is a bracket which requires an explanatory or auxiliary view to show the exact shape of one part.

Fig. 2A. 33 is a slanting base which needs the definite dimension information contained in an explanatory view to describe it completely for fabrication.

Sometimes it is difficult to show an object by means of all the usual outlines - because to do so would result in a very confusing drawing with too many lines. In such cases sections may be used. A section shows what the object would look like if it were sliced in two parts and the part nearer the reader removed. A section is really a picture drawing used only where needed to clarify the instructions and indicated by cross hatching (fine cross lines). The section may be located on the drawing proper or may be a separate view and so marked. The plane of cutting is indicated by the cutting plane line, marked with letters such as A-A in conjunction with small arrows. The cutting plane is at right angles to the paper surface and therefore at right angles to the top surface of the view in which the line appears. It is therefore necessary to go to a view other than the one in which the line appears to show the details



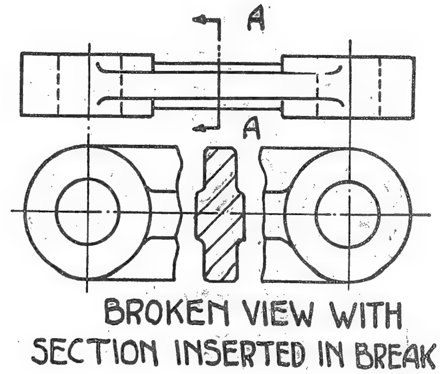
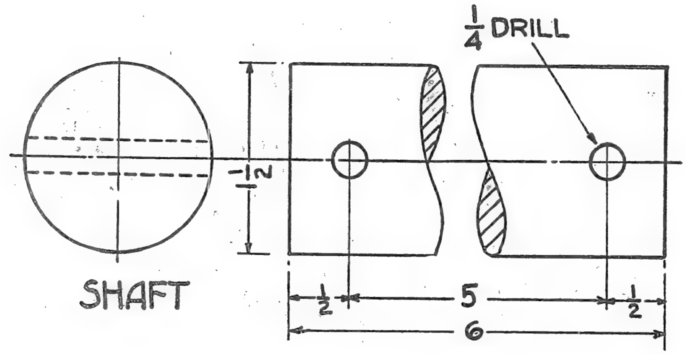


Fig. 2A. 36.

Fig. 2A. 33.



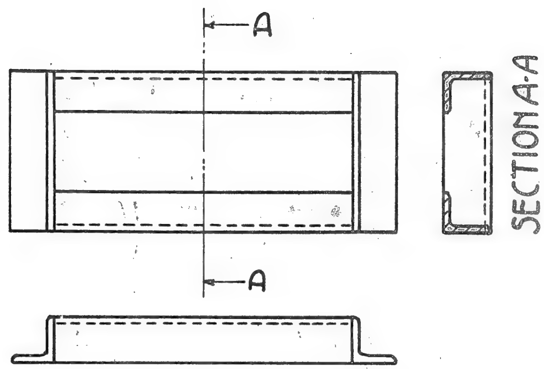
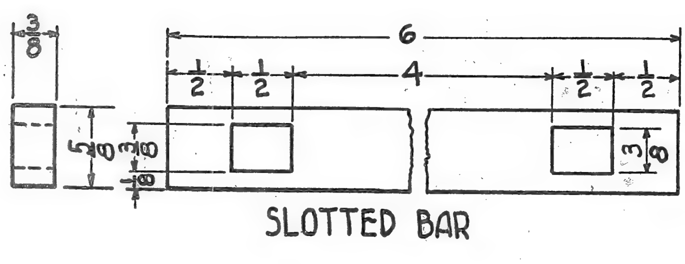


Fig. 2A. 34.

Fig. 2A. 37.



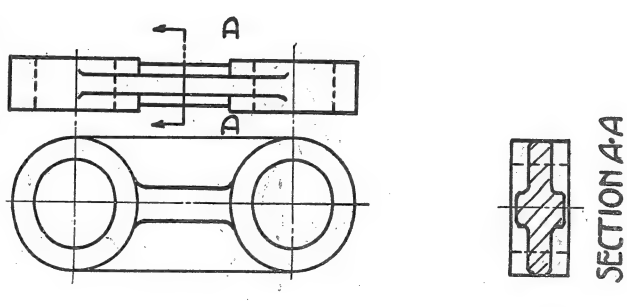


Fig. 2A. 35.

Fig. 2A. 38.

exposed by such a cut. Figs. 2A. 36 - 2A. 37 - 2A. 38 - 2A. 39 are examples of section views.

When a piece has the same dimensions for some part of its length, a segment of that unchanging section may be cut away and the ends moved closer together. The "break" line to indicate this has been discussed. Also a piece may be "broken" from a drawing if doing this would make it simpler and easier to read. Refer to Figs. 2A. 34-2A. 35 and 2A. 36.

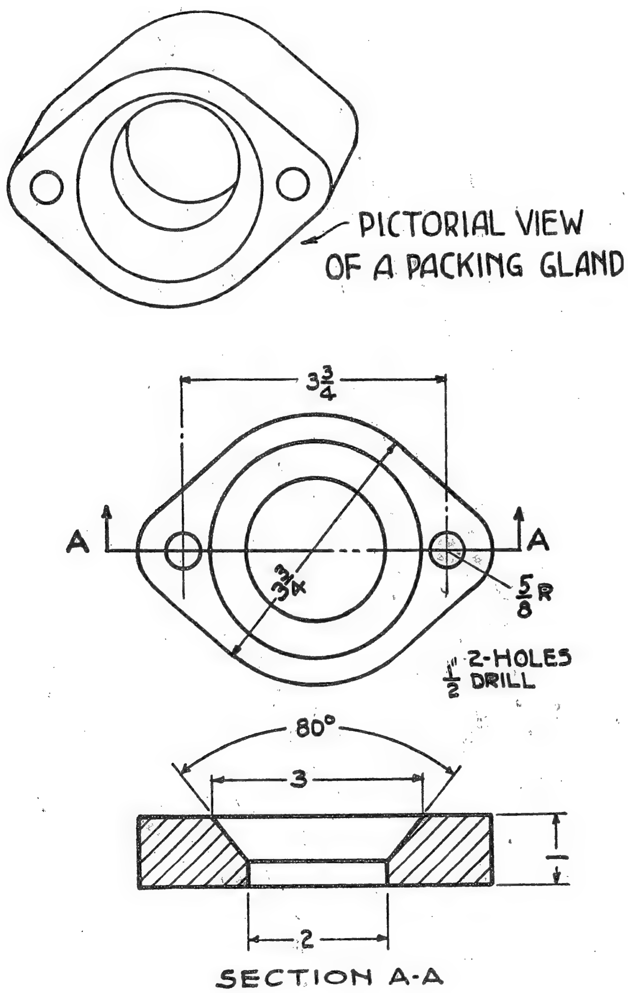


Fig. 2A. 39.

MACHINING

Sometimes machine instructions are given such as "finish". This is indicated by a small "f" on the surface requiring finishing. In some cases drill, tap and ream are marked on the drawing.

Screw threads appear in blueprints with many interpretations. In some cases very accurate pictorial drawings are made of the thread but in most drawings the thread is identified by a simple symbol and a note is added to indicate the type and size of the thread.

Fig. 2A. 40 shows some typical illustrations of screw thread symbols which need no comment. Pictorial drawings of screw threads are self explanatory.

APPEARANCE

Mention was made of the study of appearance by the use of isometric (picture) drawings. In Fig. 2A. 41 is shown a part of a base in the usual mechanical drawing. Study this carefully in reference to appearance.

While the construction of this assembly is not difficult to understand, the actual appearance may more easily be studied from some type of picture drawing. Therefore, make an isometric as in Fig. 2A. 42.

It is now possible to study the assembly with particular reference to appearance. Visualize changes which would improve the eye appeal of the construction.

Fig. 2A. 43 illustrates how the appearance of the assembly may be improved by adding small plates to the ends of the channels.

How easy it is to study eye appeal from this type of drawing. In our modern age of streamlining, appearance is an important factor in the design of a great variety of machine parts. Thus there is a valuable use for isometric or other picture drawings which is not affected by their shortcomings as fabricating or shop drawings.

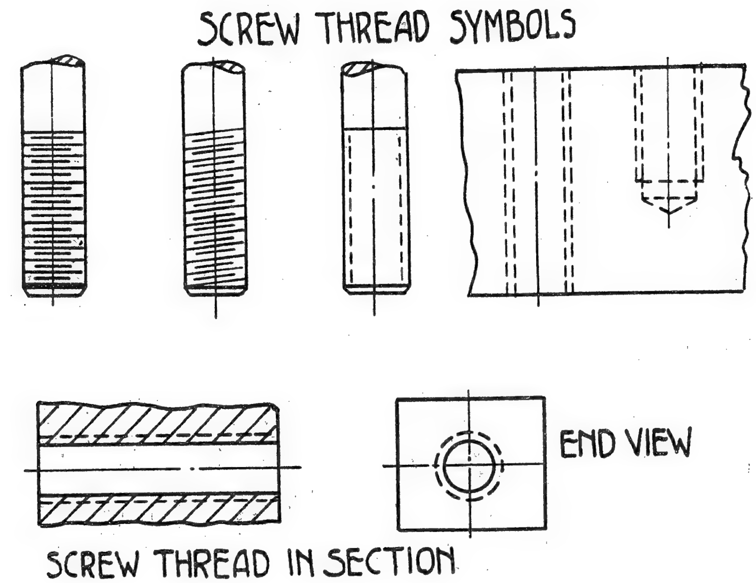


Fig. 2A. 40.

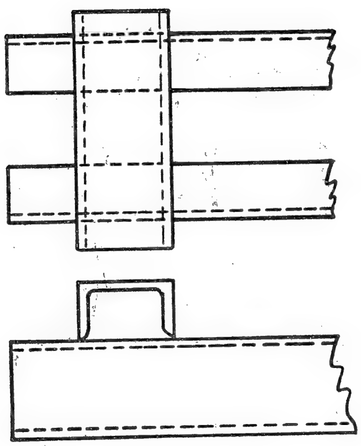


Fig. 2A. 41.

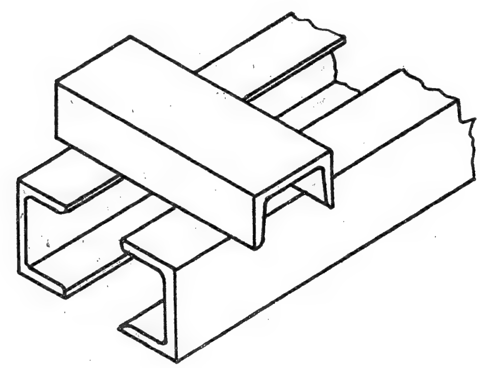


Fig. 2A. 42.

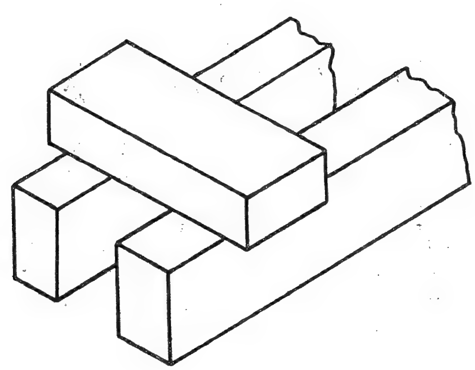


Fig. 2A. 43.

LESSON 3

ARC WELDING PROCESSES

This course deals with the arc welding processes only, i.e. those which use the heat of the electric arc for the purpose of welding.

An arc is formed when current is forced by voltage across the gap between two electrodes or an electrode and the work and thereby completes an electric circuit as shown by the dotted lines in Figs. 3.1-2. An electric arc is intensely hot and is an ideal means of obtaining concentrated heat for welding. The nature of the electrode will have a small influence on the temperature of the arc but it is always somewhat over 6000°F. and may reach much higher values under certain conditions. This temperature is so great that most metals will melt when the arc is maintained for only a short period of time.

INDIRECT ARC

Maintaining an arc between two similar electrodes as in Fig. 3.1 may be termed the Indirect Arc Method. This is the method employed in Atomic Hydrogen and Twin Carbon Arc Welding. In the case of atomic hydrogen welding the electrodes are made of the metal tungsten in the form of wire, and in the case of twin carbon arc welding, of graphite or carbon rods. Neither carbon nor tungsten are melted by the heat of the arc and are consumed very slowly. It is principally because of these characteristics that they are used.

DIRECT ARC

When the arc is maintained between an electrode and the object being welded, this is called a direct arc and the part being welded is usually referred to as the work (see Fig. 3.2).

In neither of the cases shown in Figs.3.1-2(a) is any metal being added. The metal of the joint itself is being melted by the arc and re-solidifies to form the complete weld. Metal can, however, be added in the form of a filler rod held in the joint under the arc in the manner shown in Fig. 3.2(b). The electrodes, which are either carbon or tungsten, are not themselves deposited.

DIRECT CURRENT AND ALTERNATING CURRENT ARCS. POLARITY.

The welding arc may be produced from a source of either direct or alternating current. Henceforth in this lesson direct current will be indicated by the letters DC, and alternating current by AC.

The choice of AC or DC will be governed by the process or electrodes being used or by the metals being welded.

DC is a current travelling in only one direction (see Fig. 3.3). It may be produced from an electrical generator which can be driven either by an electric motor or a gasoline or diesel engine. It may also be produced by a rectifier, which is simply an electrical apparatus which converts AC to DC. DC arcs are very stable in operation and are very effective for

welding at low and normal welding currents.

If DC is used, the polarity of the welding circuit is important to correct procedure. The polarity of the welding current is sometimes spoken of as "straight" or "reverse". In straight polarity, the electrode is negative and the work is positive. In reverse polarity, the electrode is positive and the work is negative.

AC is a current that continually reverses direction as dictated by the cycles of the electric power generator. When welding with AC, half the time the current flows from the electrode to the work while the other half the time the current flows from the work to the electrode (see Fig. 3.4). If the current is 60 cycle, each second there are 120 moments, as the current changes direction, when there is no flow of current (see Fig. 3.5).

AC is usually obtained from a transformer welding machine, an efficient source of such supply. The AC arc is satisfactory for most arc welding operations especially in the normal and high amperage ranges. It is not suited for all non-ferrous metals.

THE SHIELDED AND UNSHIELDED ARC

When metal is melted in air it becomes contaminated with oxides and nitrides produced through contact with the gases, oxygen and nitrogen. Metal so exposed has not the quality of metal that is protected from these gases. For high quality welding it is therefore desirable to protect or shield the molten metal both within and under the arc.

Shielding may be accomplished by coating the electrode with a flux or by enveloping the arc with an inert gas or a special type of granulated flux or slag. If the electrode is uncoated or the arc is not otherwise protected, it is called unshielded or bare wire welding. If the electrode is coated, it is called coated or covered electrode or shielded arc welding (see Figs. 3.6, (a) and (b)).

SHIELDING AND SHIELDED ARC PROCESSES

A. Flux Shielding

1. Extruded Flux Coated Electrodes for Manual Welding

The most common welding process (see Fig. 3.6(b)). For description see "Manual Metal Arc Welding".

2. Extruded Flux Coated Continuous Wire for Automatic Welding

An automatic welding head is shown in Fig. 3.7. The coated electrode wire is coiled on a reel 'a' and automatically fed towards the work to be welded 'b' by means of feeding rollers 'c', after passing through a set of straightening rollers 'd'. Below the feeding rollers 'c' the electrode wire is held by roller 'e' against a motor driven cutter in housing 'f', which mills a slot in the coating. This slot allows the springloaded brushes 'g' to transmit the welding current to the electrode metal. The brushes are close above the arc, thus reducing to a minimum the current-carrying length of electrode wire. A suction hose 'h' is provided for withdrawing

welding fumes and milling chips. All settings are adjusted on control panel 'j'.

3. Precision Stranded (twisted) Coated Continuous Wire

Such a wire is used by certain semi-automatic welding systems. Fig. 3.8 shows a section of filler wire and Fig. 3.9 shows this system in action.

4. Continuous wire Coated with Adherent Magnetic Flux

A bare wire is fed through a hand-held hopper containing magnetic flux. The flux clings to the wire as it leaves the hopper (Fig. 3.10) because a magnetic field has been established by the welding current flowing through the wire. Thus the electrode wire reaches the arc with a flux covering which gives it some of the advantages of the coating on a manual electrode. The process is used for welding as well as for build-up purposes and hard facing.

5. Granular Flux Shielding

Here wire, arc and weld are covered and shielded by a blanket of granular, fusible material known as melt, flux, welding composition, etc. For purposes of simplicity the material will be referred to as "flux".

Because of the hidden or submerged arc the process using granular flux is called "Submerged Arc Welding". (For details see Fig. 3.11).

The shielding material performs four important functions:

(a) Prevents weld metal contamination from the air and so tends to produce high quality deposited metal.

(b) Acts as a "dam" to shape the weld.

(c) Slows down the cooling of the weld and produces a more ductile weld deposit.

(d) May alloy with and favourably alter the weld metal or simply purify and clean the deposit.

The deposited flux becomes molten under the heat of the arc, and being displaced by the heavier deposited weld metal, floats to the weld surface and fuses into a glass-like covering over the molten metal.

B. Inert Gas Shielding

In a great variety of inert gas arc welding processes the wire, arc stream and molten metal are protected by an envelope of inert gas, such as helium, argon, or various mixtures of these as well as some active and reactive gases, e.g. oxygen, carbon dioxide, etc. Fig. 3.12 shows an example of inert gas shielding.

There are actually two different types of inert gas, metallic arc

welding, one type termed tungsten-arc inert-gas welding or, for short, "Tig" (with non-consumable electrode) and the other - metal-arc inert-gas welding or "Mig" (consumable electrode).

"TIG" Welding Process (See Figure 3.12(a))

The Tig process with a non-consumable or relatively permanent electrode is similar to other metal arc welding processes in that the metals to be joined are heated to fusion temperature by an electric arc struck between work and the welding electrode. However, as the title indicates, it differs from most of the older methods in that (1) the electrode does not melt and form part of the weld metal and (2) the inert gas provides the shield for the molten metal and the electrode.

A localized area of the metal to be welded is melted under the protective blanket of inert gas. As a rule, the weld is the result purely of the fusion of the base metal but, when necessary, filler metal, in the form of a rod or wire, can be added to the weld in much the same manner as in oxy-acetylene welding.

The non-consumable type of metal electrode may be either tungsten or thoriated tungsten, etc.

One of the most valuable gains made by the use of this process is the elimination of flux in many applications, provided that proper equipment and technique are employed.

AC or DCSP (straight polarity) or DCRP (reverse polarity) are all used in Tig welding. Each type of current has characteristics which make it most suitable for certain materials and job applications.

Manual, semi-mechanized and automatic equipment are all at present in use.

"MIG" Welding Process (See Figure 3.12(b))

Inert gas metallic arc welding with consumable electrodes or the Mig process has characteristics which are similar to those methods using tungsten electrodes, but at the same time it extends the use of the process to the welding of heavier thicknesses and thereby broadens greatly its possible applications.

This process consists of continuously feeding a bare or processed wire from a suitable holder, torch or gun. This filler wire which serves as the electrode, carries the welding current and maintains a welding arc between the end of the wire and the work. Wire is continuously fed to the arc at the rate at which it is consumed and transferred to the base metal. The arc is shielded by an inert gas, or CO_2, or other gases, and mixtures of gases and fluxes, which flow from the nozzle of the gun through which the electrode also passes. A contact area through which the electrode passes impresses the pre-selected welding current upon the electrode wire. The current causes the wire to melt at the precise rate at which it is fed. The shielding gas issuing from the nozzle protects the weld metal deposit, and the continuously fed electrode, from contamination by the surrounding atmosphere.

The process has been applied to production work using manual semi-automatic (manually guided) and fully automatic equipment.

Argon and argon oxygen mixtures are used as shielding gases. Carbon dioxide, however, is being used extensively for welding plain carbon steel and some low alloy steels. A combination of carbon dioxide and flux shielding is being used in many variations of the process. Development of these flux/gas semi-automatic processes is along three lines viz., the use of a bare wire with magnetic flux, flux-cored tubular and continuous covered electrodes, carbon dioxide being used as the gas shield in each case.

C. Atomic Hydrogen Shielding

This is an indirect arc, gas shielded fusion welding process that may or may not require filler metal and pressure to complete the weld joint. The original source of heat is an arc drawn between two tungsten electrodes. Hydrogen gas is fed into and about the arc and serves several purposes. First, it protects the molten metal of the weld from contamination by the air, and secondly serves to cool the electrodes. It further has the unique characteristic of breaking down from molecular hydrogen to the atomic state under the heat of the arc. In doing so it draws energy in the form of heat from the arc and re-liberates this heat on returning to the molecular state at the cooler surface of the material being welded. It is this heat of the gas that is used for welding and the process as a consequence is somewhat similar to other gas welding processes such as oxy-acetylene. The temperature of welding is not necessarily the arc temperature but may be varied by increasing or decreasing the distance of the torch from the surface of the work.

The apparatus, in its simplest form, consists of a 2000 lb. pressure hydrogen cylinder, a two stage gas regulator, a moving coil transformer welder equipped with a solenoid gas valve, a starting switch and the special electrode holder. It is usually supplied with automatic controls and fixtures.

Fig. 3.13 is an illustration of the special electrode holder used in manual welding. The position of the tungsten electrodes may be altered so that the arc shape and size may be either concentrated or spread over the plate surface.

Atomic hydrogen welding is a special process for producing good quality welds on 'hard to weld' metals, either manually or automatically. This process has, to a considerable extent been replaced by inert gas welding, but is still used to produce high quality welds in stainless steels, monel, inconel, nickel, copper and brass alloys. It is particularly successful in the welding of tools and dies and this constitutes its greatest use at the present time.

D. Flux Plus Gas Shielding

1. Magnetizable Flux plus CO_2 Shielding

This process combines a continuously fed bare wire, a magnetic flux, gas and direct current. The principle of this process which is

semi-automatic is shown diagrammatically in Fig. 3.14. A bare steel wire is fed through a flexible tube to the torch. The magnetizable flux is placed in a dispenser (shown in Fig. 3.15). The flux is fluidized at the dispenser in a stream of welding quality carbon dioxide gas.

2. Continuous Covered Electrode Wire with CO_2 Shielding

This automatic process is similar to other processes using continuously and automatically fed wire with an additional gas shield. A self-propelled machine is shown in Fig. 3.16.

The combination of flux coating and gas shielding gives considerably higher welding speeds than can be attained with either flux or gas alone, using currents up to 1200 amp. The process gives deep penetration. Slag is almost self-releasing. Surface cleaning is not so critical as with other processes.

E. Flux Cored Wire (with or without additional gas shielding)

1. First Variation of the cored wire is shown in Fig. 3.17 - a cross section of the electrode wire and in Fig. 3.18 - a scheme of the process. Flux cored electrodes are tubular continuous rods with several internal folds designed to hold and distribute the flux core material evenly. Additional shielding is CO_2.

2. Second Variation of the flux cored electrode wire is shown in Fig. 3.19 - an enlarged view of the electrode wire made by forming a steel strip into a cylindrical tube and filling the interior with a specially prepared core material containing the degasifiers, scavengers and slag formers. Additional shielding is CO_2. Fig. 3.20 shows a scheme of the process.

3. Third Variation of the flux cored wire is given in Fig. 3.21 showing a vapor shielded open arc. All of the welding materials - gas shield, fluxing ingredients, deoxidizers and filler metal - are contained in the core or electrode sheath. It produces welds whose mechanical properties are similar to those made by the submerged arc and is used mostly for relatively thin material and in single passes.

The arc is established between the continuously fed consumable wire and work. Filler metal, flux and deoxidizers spray into the molten crater on the base metal while shielding ingredients vaporize to keep out harmful elements of the atmosphere.

MANUAL METAL ARC WELDING

Manually operated metallic or metal arc welding with stick electrodes is still the most common welding method as it allows freedom of control and design for the least cost of equipment and labor.

The knowledge of joint design, arc action, heat control and metal reaction gained from manual metal arc welding has been of great value in developing all other variations of the arc welding process.

In operation, an arc is struck between the end of the electrode and the metal to be welded, variously called the parent metal, base metal or work. The electrode metal progressively melts and is carried across the arc into the weld joint and fuses with the molten base metal.

If the operator utilizes a proper technique, the electrode metal can be deposited overhead or vertically almost as easily as in the flat position. This is possible since the arc force, like a garden hose, will push the molten electrode metal in a spray of globules in any direction.

Arc welding, like the electric arc furnace, actually supplies a very high grade cast deposit usually purer in chemical composition than the base metal and often of superior mechanical properties.

To increase the rate of welding should be a prime objective. Positioning the work for down hand welding, the use of large electrodes and high currents and taking advantage of the high deposition rate of iron powder electrodes provide the means for doing this.

Manual metal arc welding is extensively used for the manufacture and repair of pressure vessels, pressure and oil line piping, field storage tanks, bridges, buildings, ships, railway cars, trucks and automobiles, all types of machine bases, aircraft parts, nuclear power stations and a great many miscellaneous products.

Special coated electrodes are available for metal arc welding of castings of grey iron, steel, nickel, copper, aluminum and bronze. Other electrodes are available for the welding of rolled sections in low, medium and high carbon steels, low alloy high strength steels, stainless alloys, nickel and copper base alloys, aluminum, magnesium and other non-ferrous alloys.

Metal arc welding is valuable for hard surfacing all types of products exposed to combinations of wear, impact, heat and corrosion. A great many single purpose alloy electrodes are designed for such applications.

Some coated arc welding electrodes are designed for use only with direct current. For bare metal electrodes, direct current with straight polarity, (i.e. electrode negative) must be used. Other electrodes are designed specifically for alternating current; on the other hand, these will usually work satisfactorily on DC, but in this case the polarity used should be the one recommended by the electrode manufacturer. (For more on electrodes - see Lesson 5, Arc Welding Electrodes).

Manual metal arc welding, with either shielded electrode or bare rod, (see Fig. 3.6) requires experienced welding operators. Simple welding operations may be taught in a few days, but an operator capable of making satisfactory welds in all positions, on a variety of metals, is a highly skilled artisan usually of long experience.

AUTOMATIC OR MACHINE ARC WELDING

Automatically controlled metal arc welding has been in use for over thirty years on general and mass production items such as butt joints in pipes and tubes, boilers, containers and tanks, as well as fillet welds on a great variety of machinery, girders, beams and other structural work, as a means of improving weld quality and reducing labor costs. Usually the arc is shielded by one or other of the methods already mentioned.

Little or no skill is required for automatic welding. The operation is performed throughout by automatic controls and mechanisms. Once set these controls determine the speed of welding, the rate of wire feed, the current and voltage values and the position of the welding head in relation to the seam. However, all these functions may be varied by the operator during the course of welding if he deems it necessary.

The head may be mounted on a travel carriage and automatically passed along and over the seam to be welded, or it may remain stationery while the seam passes by or underneath it. In the latter case it is, of course, the work itself which is moved. To achieve a high degree of automation it is often integrated with other processes such as forming and bending.

The advantages of automatic operation are usually faster welding with less waste of material and better weld quality. However the mechanisms are expensive and usually designed for a single purpose operation.

Semi-automatic welding is also employed wherein the operator moves a light head or torch along the joint to be welded. Currents and speeds cannot be as great as for fully automatic welding and more skill and energy is required of the operator. However the Units are cheaper and, being smaller and lighter, are often more adaptable. Deposition rates are greater than for manual welding and frequent stops to change electrodes are not necessary.

It is becoming customary to designate a tradesman skilled in manual welding or in the use of semi-automatic equipment as a "weldor" and one who operates an automatic welding machine as a welding operator. These terms are not necessarily followed throughout this course, however, and the phrase "welding operator" is commonly used to indicate a manual operator as well as a machine operator.

SUMMARY

SHIELDED ARC WELDING PROCESSES AND THEIR APPLICATIONS

The prime object of nearly all recent developments in arc welding, particularly when related to the welding of mild steel, is to achieve an increase in productivity. This can be done in two ways; firstly, by developing processes with an inherently high rate of weld metal deposition, and secondly, by using these processes in such a way that the arc utilization is high, so that the time gained by high deposition rates is not lost in handling operations.

Development in manual electrode welding is aimed principally at combining a high deposition rate with high metallurgical quality. Manual welding should be carefully considered for non-repetitive or low production jobs, for small welds or odd shapes that would require extremely complicated fixturing. Semi-automatic welding offers more possibilities, in that high current densities (amps per sq. inch) giving high deposition rates with no stoppages to change electrodes are available. Semi-automatic welding may also be a more practical answer for medium production runs where there is considerable footage of welding, either in long welds or repetitive

short welds. It is also used on applications where more penetration is required than can be obtained through manual welding. Manual guiding and simple low cost fixturing permits its use on irregular shapes and on work that is too large to be positioned under an automatic head.

When the volume of welding warrants the capital investment on equipment and fixturing for the fully-automatic, and where fit-up, shape of parts and access to the joint are satisfactory, it is possible to take advantage of the high speed, high quality and reliability of fully-automatic welding at a great reduction of labor cost. Developments in this field are principally towards the application of the process to give high utilization of the arc and a reduction in the time lost in handling and preparing the work.

From the foregoing (Shielding and Shielded Arc Processes) the student will have learned that the limitations of shielding either by flux or gas alone can largely be overcome in processes in which flux and gas shielding are used in conjunction. In such a process, the gas protects the molten metal from the air and provides a suitable atmosphere in the arc region, whilst the flux supplies the necessary deoxidants and any alloying additions required. As a large part of the metallurgical control is derived from the gas, the flux can be designed to give good operational properties and easy deslagging. The arc is a visible one (unlike the submerged arc welding process) and since the deoxidants are contained in the flux, expensive core wires of special composition may not be required as in processes shielded by gas alone. Thus, certain semi-automatic processes operating on the flux/gas principle combine the use of cheaper electrodes, shielding by CO_2, with high deposition speeds.

The metallic-arc inert-gas welding process (Mig) can be operated in many ways and with various techniques. The method selected may depend upon the type of gas used - inert gas or carbon dioxide. The particular application and available equipment may determine whether manual (semi-automatic), automatic or spot welding equipment is used. In addition a modification of the carbon-dioxide shielding system, employing magnetic flux or a flux-cored wire, may be selected. Each application has to be considered separately, and all factors should be taken into consideration before a process or technique is specified.

The relative simplicity of the Mig equipment and the welding operation itself have been contributing factors in adoption of the manual (semi-automatic) application of the process. The method provides a satisfactory means of joining a variety of metals and alloys and is adaptable to both shop and field use.

Fully-automatic operation of the Mig process is used to a considerable extent where welds are repetitive and identical in nature. This method, as it was mentioned before, is often used for welding plain carbon and alloy steel components.

Carbon-dioxide gas shielding is used in many manufacturing operations where high welding speed and low part cost are imperative (mostly with fully-automatic equipment).

BIBLIOGRAPHY

1. Shielded Inert Gas Tungsten Arc Welding Process - Shielded Inert Gas Metal Arc Welding Process - Metal Inert Gas Welding of Mild Steel - see The Welding Digest, April, August and December 1958, published by Canadian Welding Bureau.

2. Recent Developments in Inert Gas Welding, by F. G. Pilia, The Welding Journal, January 1956.

3. Why Weld Automatically? by I. C. Fitch, The British Welding Journal, July 1958.

4. How to Use Semi-automatic Submerged Arc Welding, by R. A. Wilson, The Welding Journal, June 1955.

5. Automatic Arc Welding as a Production Tool, by J. A. Lucey and others, British Commonwealth Welding Conference, London, Saltburn, 1957.

6. Carbon-Dioxide-Shielded Consumable-Electrode Arc Welding by G. R. Rothschild, The Welding Journal, January 1956.

7. Dip Transfer CO_2 Welding of Mild Steel and Low Alloy Steels, Welding Design and Fabrication, July 1959.

8. The Principles of Modern Arc Torch, by R. M. Gage, The Welding Journal, October 1959.

9. A New CO_2 Welding Process, by R. F. Chouinard and R. P. Monroe, The Welding Journal, November 1957.

10. Studies of Welding Arcs Using Various Atmospheres and Power Supplies, by T. B. Hazlett, and G. M. Gordon, The Welding Journal, August 1957.

11. Gas Shielded Welding of Mild Steel, by R. E. Jahn and L. M. Gourd, British Oxygen Research and Development Ltd., Commonwealth Welding Conference, London, Saltburn, 1957.

12. Predetermination of Preheat and Postheat for Submerged Arc Welding by C. A. Jackson and A. E. Shrubsall, The Welding Journal, November 1956.

13. A Selection Guide for Submerged Arc Welding Methods, by M. N. Vuchnich, Canadian Welder, August 1958.

14. Arc Welding History, Processes, Equipment and Nomenclatures, The Lincoln Electric Co. Procedure Handbook of Arc Welding, Cleveland 17, Ohio.

15. The Welding Encyclopedia, Chicago, Illinois.

16. Gas, Arc and Resistance Welding Processes, AWS Welding Handbook - Section Two, New York, N.Y.

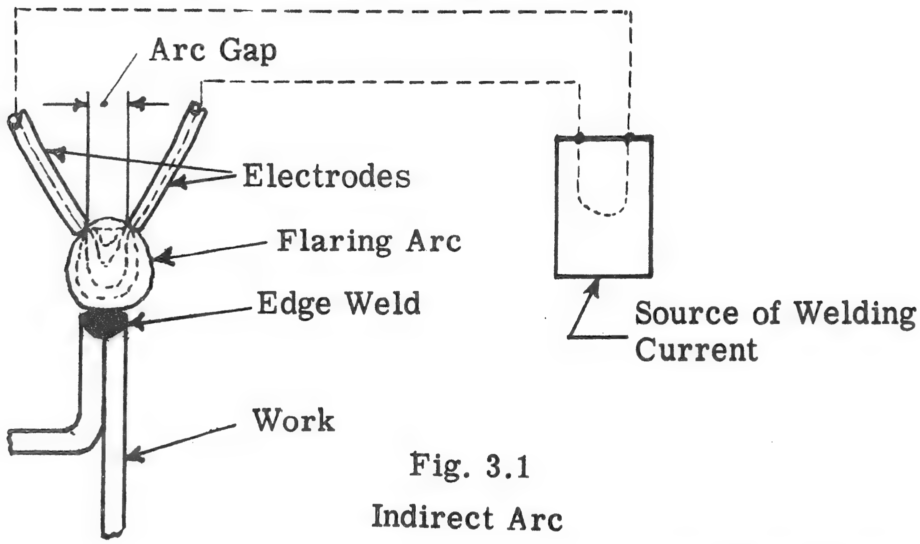
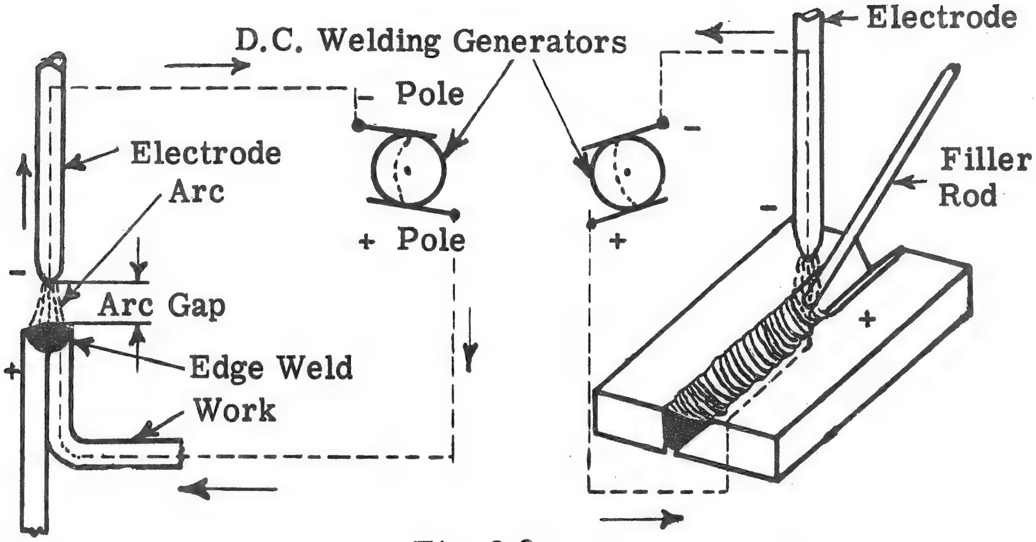
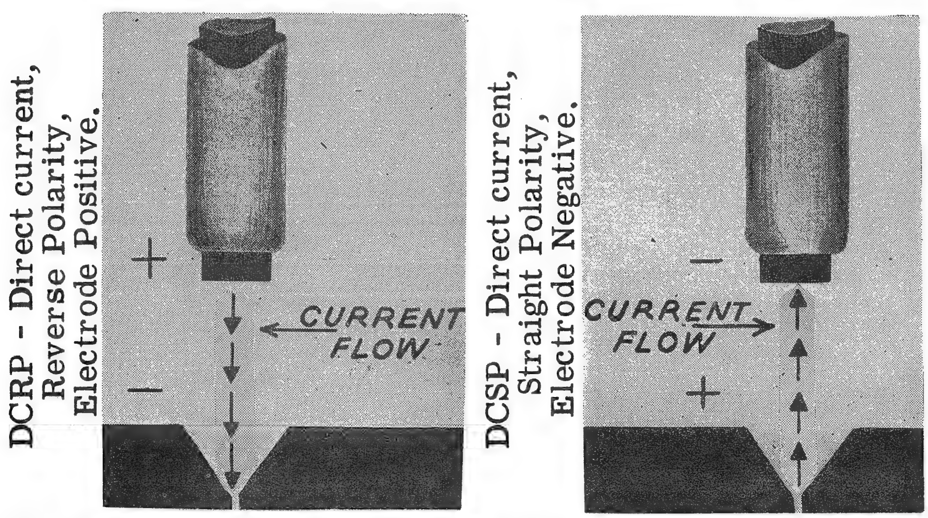


Fig. 3.1
Indirect Arc



(a) Fig. 3.2 (b)
Direct Arc



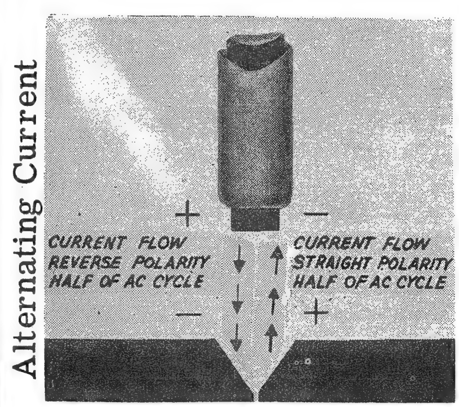


Fig. 3.3. Straight and Reverse Polarity.

Fig. 3.4. Alternating current flows in both directions alternatively. Polarity reverses 120 times per second with 60 cycles AC current.

Note:

Early welding was carried out chiefly with bare wire which worked best with the electrode negative. Later coated electrodes were developed which often worked best with the electrode positive. Hence the term reverse polarity as opposed to normal or straight polarity.

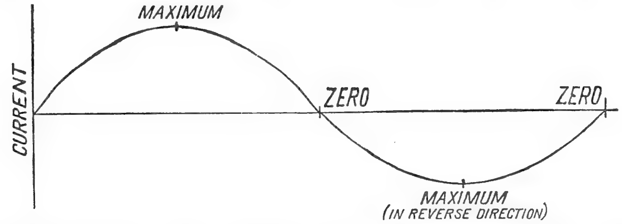
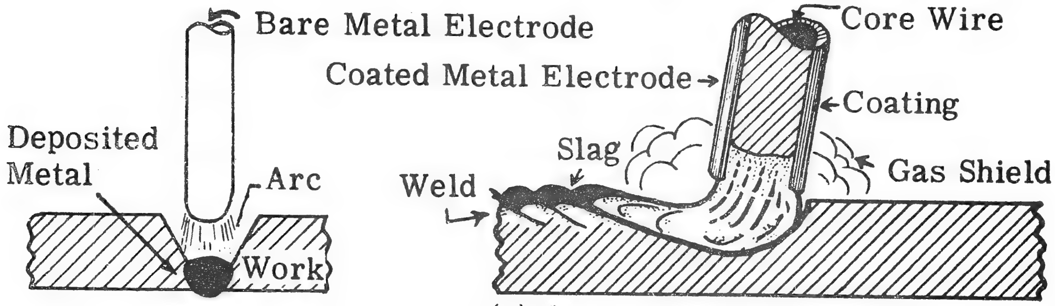


Fig. 3.5 - Each second of 60 cycle AC contains 120 moments of zero or no current flow, which may cause the arc to go out. The surge to maximum values tends to expel globules of spatter



(a) Unshielded Arc

(b) Shielded Arc (Covered Electrode)

Fig. 3.6
Metallic Arc Welding

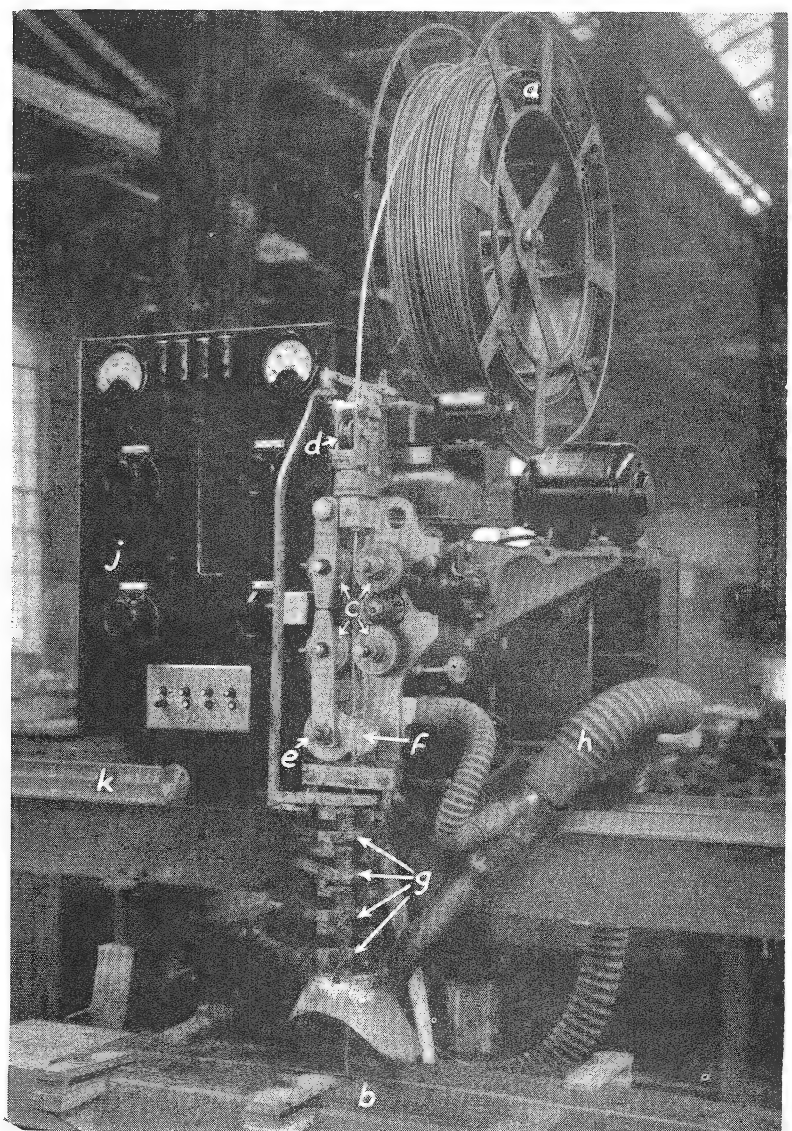


Fig. 3.7
Automatic Welding Head for Coated Continuous Wire

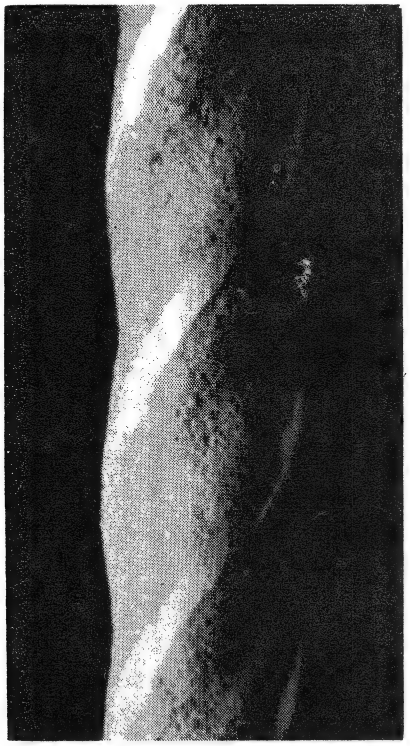


Fig. 3.8
Section of a stranded (twisted) coated continuous wire (mild steel). AC or DC current can be used

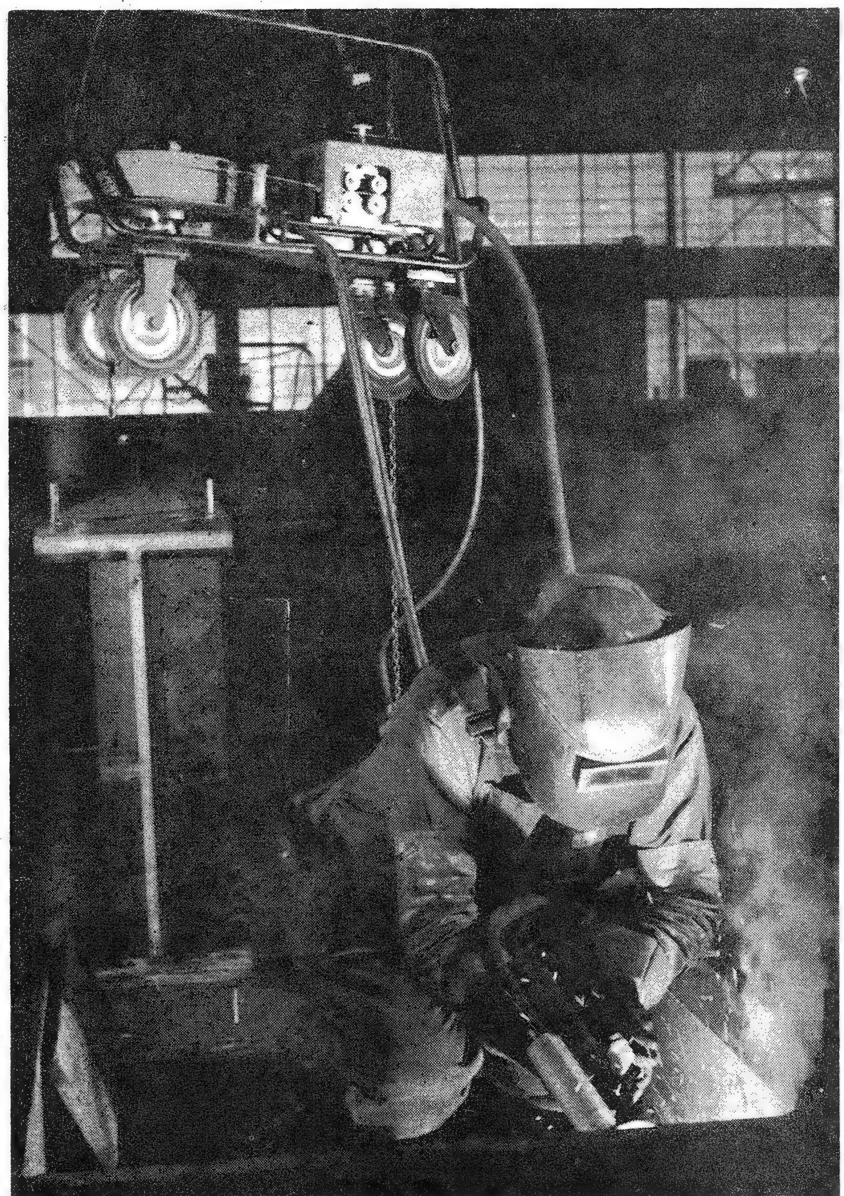


Fig. 3.9
Stranded (twisted) wire unit at work. (Semi-automatic - manually guided)

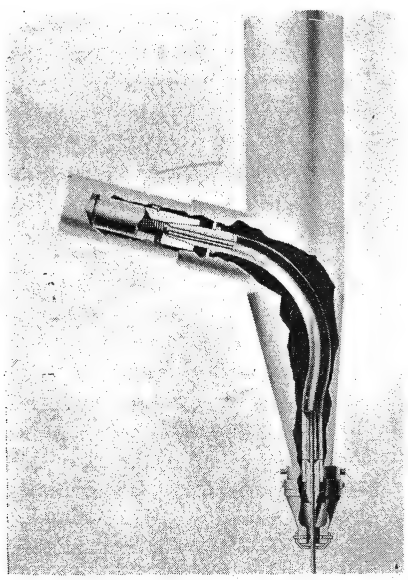


Fig. 3.10
Magnetic Flux Process Nozzle

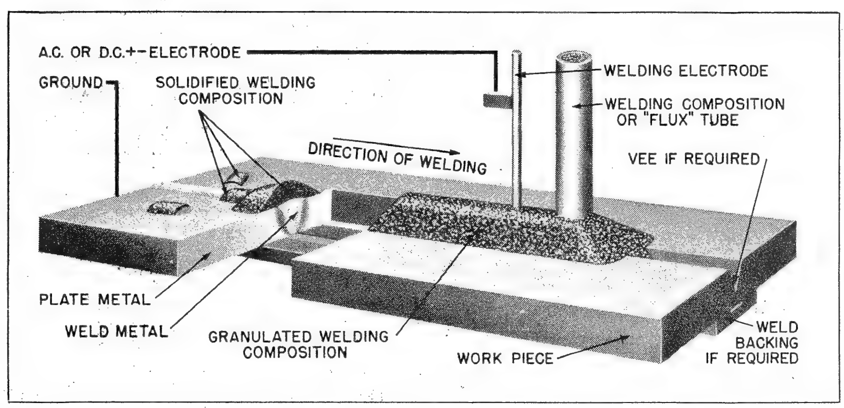
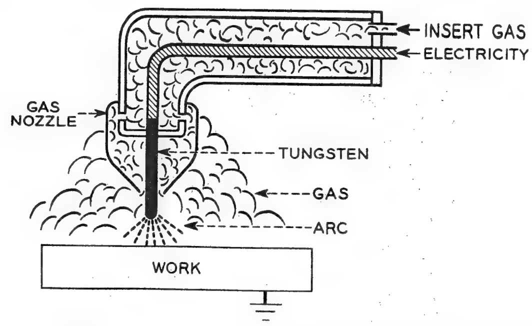


Fig. 3.11
Submerged Arc Welding Process (Granular flux shielding)

Fig. 3.12 - right
Inert Gas Shielding



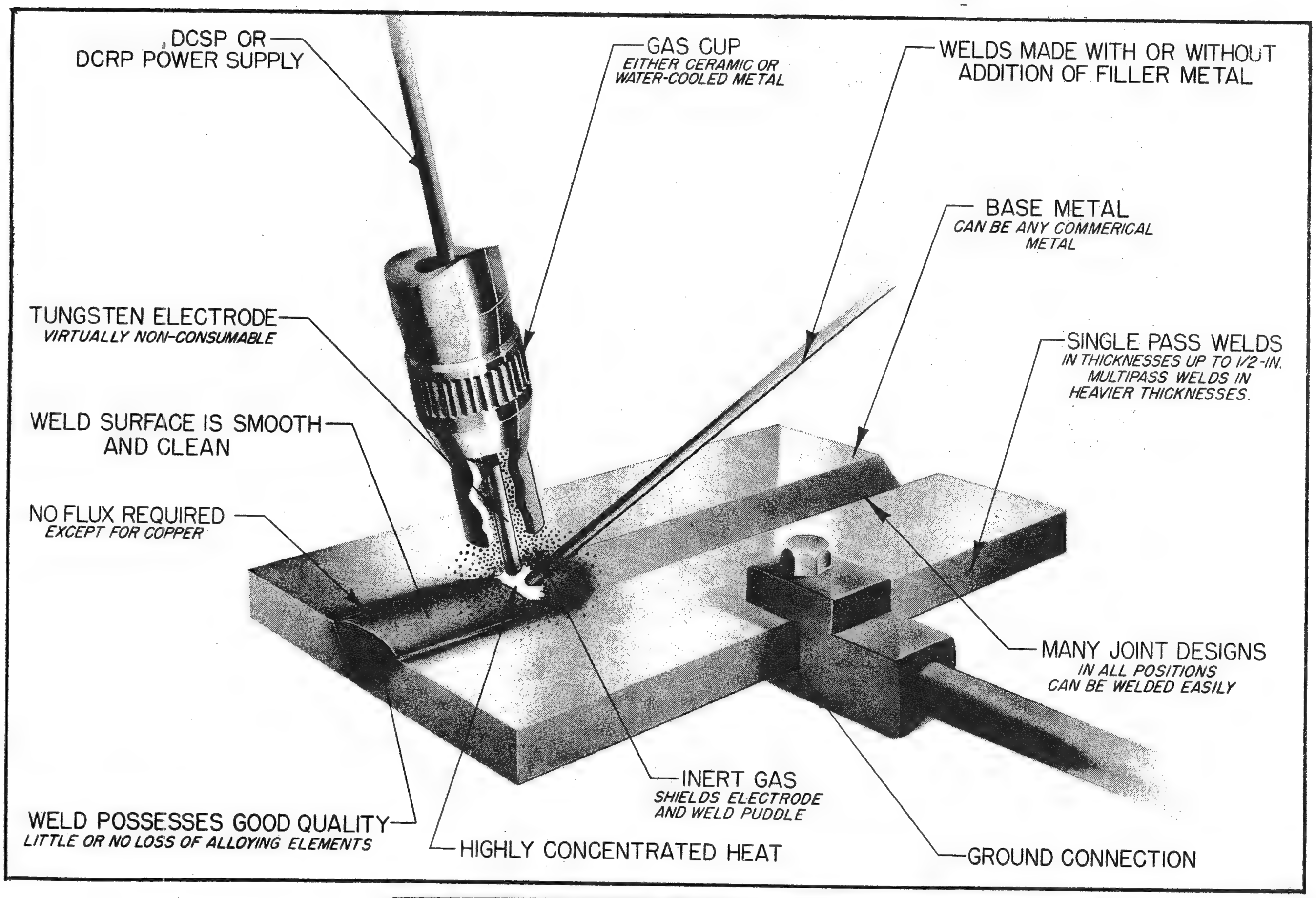


Fig. 3.12(a)
Essentials of the
Tig Process

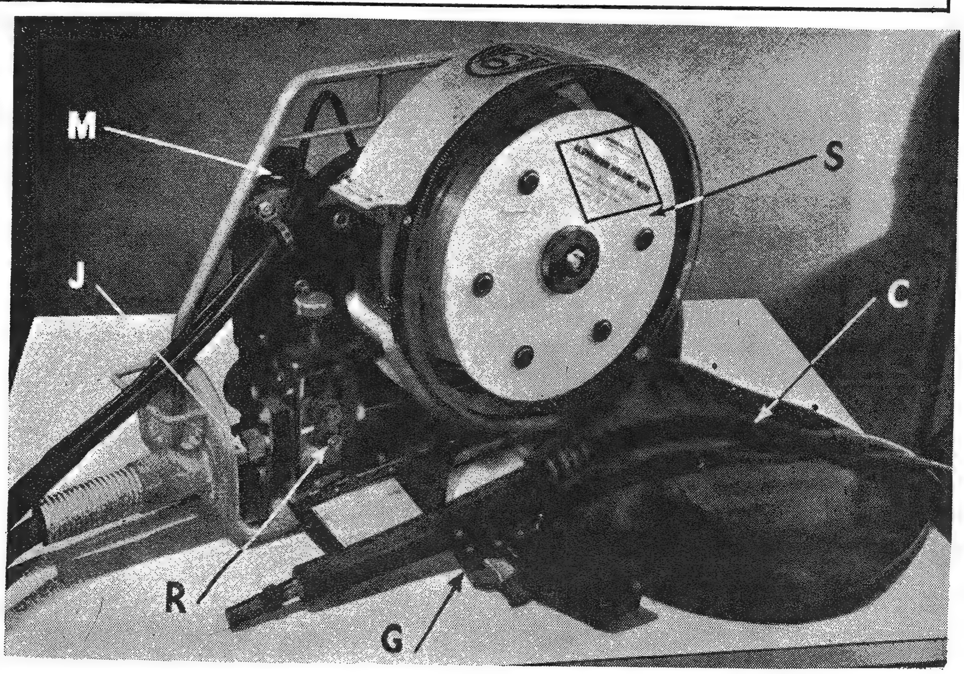


Fig. 3.12(b) - right
Mig Process Equipment. The electrode wire is carried on spool 'S' and fed by drive rolls 'R' through the flexible casing 'C' to the welding gun 'G'. The drive rolls are rotated by an electric motor 'M'

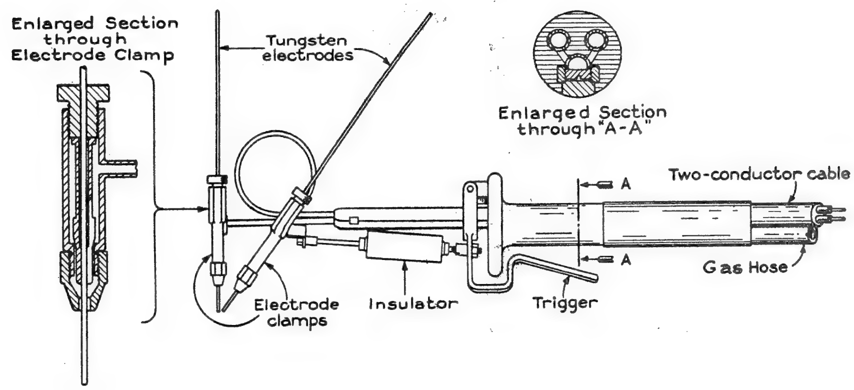


Fig. 3.13
Electrode Holder for Manual Atomic Hydrogen Welding

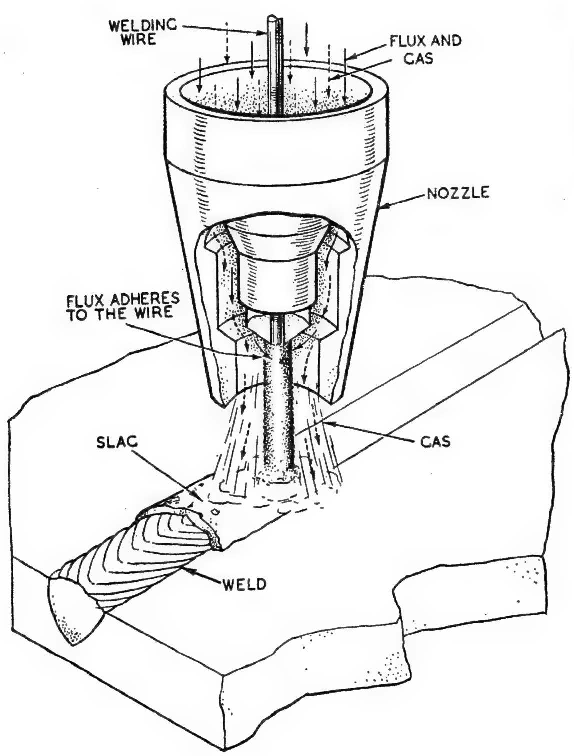


Fig. 3.14
Magnetic Flux plus CO_2 Shielding
of
Bare Electrode Wire

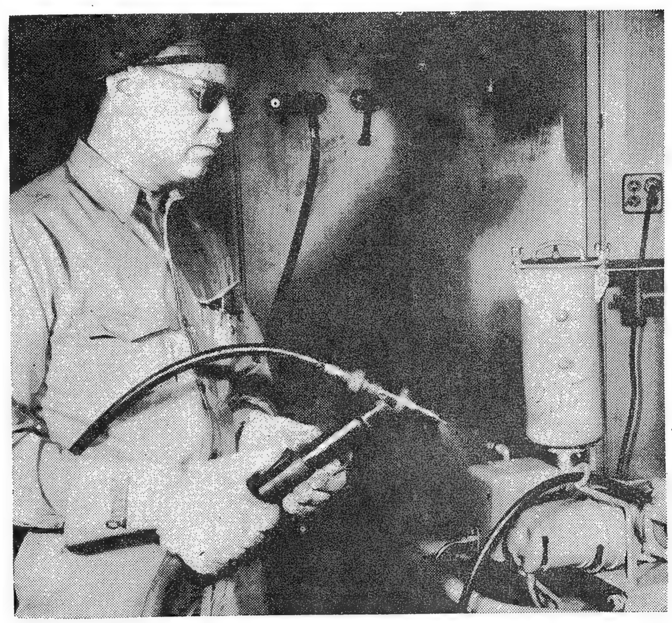


Fig. 3.15
Welding wire and flux issue simultaneously from the welding torch nozzle as the operator pushes the 2-way control switch on the torch handle. When welding current is flowing (not on in this picture), the flux is magnetically attracted to and coats the wire

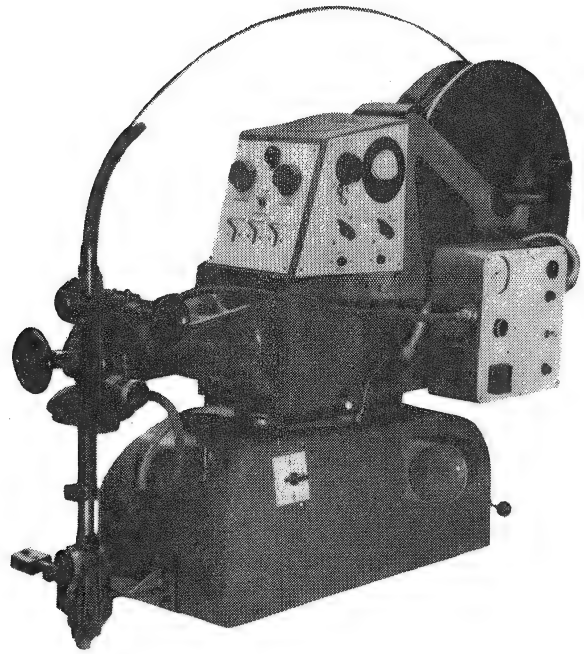


Fig. 3.16
Self-propelled machine equipped for welding with CO_2-shielded continuous covered-electrode process

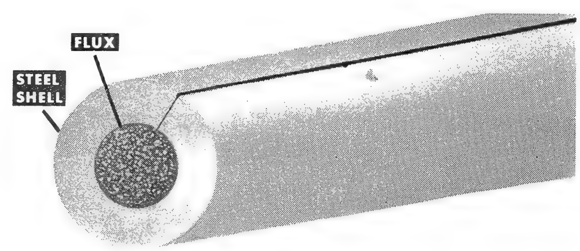


Fig. 3.17 Fig. 3.19
Two types of flux-cored wire

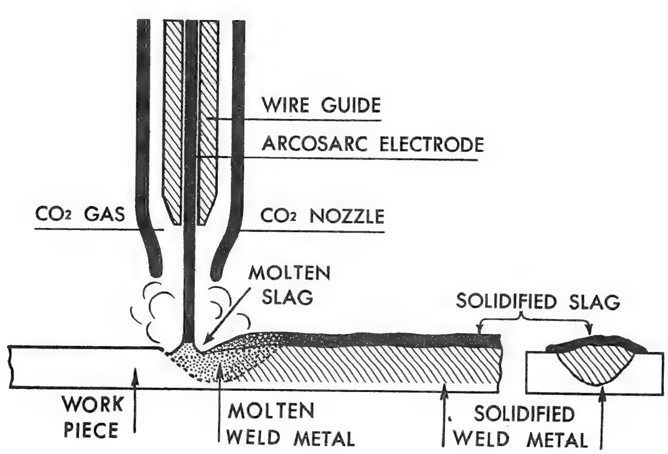


Fig. 3.18
Schematic diagram description of equipment using a flux-cored electrode wire shown in Fig. 3.17

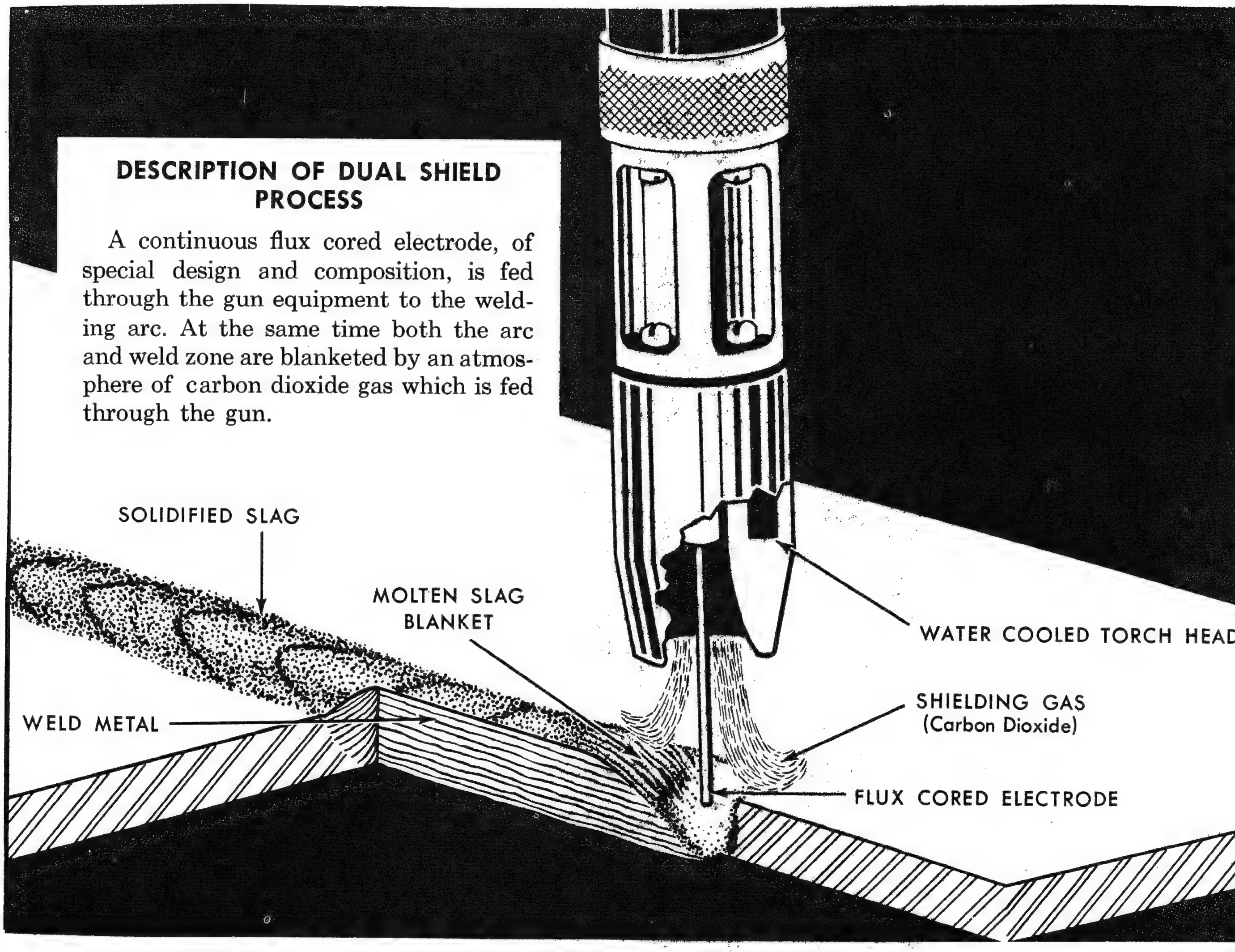


Fig. 3.20
Cross section of process using wire shown in Fig. 3.19 in conjunction with gas

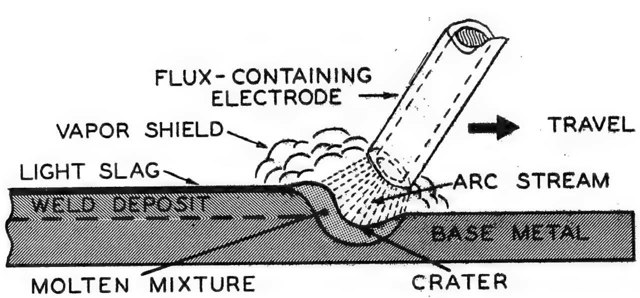


Fig. 3.21
Flux-cored wire used without additional gas protection

LESSON 4

ARC WELDING EQUIPMENT

To understand arc welding equipment, it is necessary to understand what is demanded of it. This, in turn, requires a knowledge of the conditions necessary to establish and to maintain a metallic arc. Fig. 4.1 illustrates the sequences in establishing and maintaining an arc with a bare wire electrode.

In (a) the electrode is touched to the work. This constitutes a short circuit. A surge of current results inasmuch as the flow of current is unrestricted. There is a complete metal path for the current with little resistance, through the copper cable to the welding rod and through it to the work and back through the ground cable to the machine whence it came. This surge of current heats up the tip of the electrode to the point at which a small amount of metal vaporization takes place. On withdrawing the electrode a high voltage is required to force the arc across the gap, as air resists the flow of current to a much greater extent than metal. However, the slight amount of vaporized metal from the heated tip assists in providing an easier arc path and a minutely short arc is formed. Immediately following this the air is ionized by the arc which further reduces its resistance and the arc becomes established at the length indicated at (b). Thereupon, as a result of the heat of the arc, the end of the electrode starts to melt as at (c). An elongated globule is formed as at (d) and the arc length is considerably reduced. This globule increases in size until it touches the work and another short circuit occurs, as shown at (e), and the arc is extinguished. Operators who have seen the reflection of the arc on welding booth walls will have noted the alternating light and dark periods. A dark period occurs when a globule makes contact and the arc is momentarily out. The wholly metallic circuit completed by the globule offers little resistance to flow, and another surge of current results. The surge explodes the globule off the rod, and at once the distance from the work to the end of the rod increases, rapidly establishing a new arc as shown in (f). This requires, within thousandths of a second, a high voltage to again establish the arc across this relatively great distance of air. Fortunately, at this stage, the resistance of the gap is not as great as normal because some residual air ionization will remain and some metallic vapor will still exist.

Thus it will be seen that a welding machine or source of power is required to deliver first a surge of current, followed immediately by a high voltage to establish the arc and then varying currents and voltages during the period of the globule transfer, followed again by a high voltage to maintain the arc once the globule has passed across. All these changes happen very quickly and the machine must be able to respond even more quickly.

With coated electrodes the coating helps greatly to ionize the arc path and as the globules are transferred more frequently and are minute in size, they do not result in the same variation of the arc path resistance. So it is that more carefully designed and more responsive equipment is required for bare wire welding.

The voltage force that must always be available for establishing

and maintaining the arc as it shortens or suddenly lengthens, either due to globule transfer or the operator's instability of hand, is called 'striking voltage'. Since it is the voltage maintained by the machine before the circuit is closed by touching the electrode to the work, it is also naturally called the OPEN CIRCUIT VOLTAGE (Figure 4.2). This is the voltage that will show on the voltmeter of the machine (if it is equipped with one) when the machine is running but no welding is taking place.

If this voltmeter is watched when the arc is struck, the needle will be seen to drop almost to zero. Very little voltage is required to send the current through the circuit when it is metal all the way. However, when the arc is drawn, the needle or pointer will show more voltage indicating that more is required. Further, it will fluctuate somewhat indicating the various voltages needed as the globules are transferred and the path across the arc becomes more or less completely metallic. These fluctuations of voltage are actually greater than shown on the meter as it is too slow in responding due to the inertia of its moving parts.

If the machine has a separate ammeter it may be seen that the current-indicating needle will vary also. Close observation will show that the current increases as the voltage decreases. In other words, as the metallic path is more complete the current flows more readily; more of it flows, and less voltage is required to force it through the circuit. Again, the current variations are actually greater than the pointer of the ammeter shows. Like the voltmeter, the ammeter is also slow in response and purposely so in order that it will actually show the average values. Thus, although the ammeter may show an average welding current of 130 amperes, the actual variation may be from 75 to 200 amperes. Correspondingly the average voltage shown may be around 20 volts but may actually vary from nearly zero to 30 volts or more if the operator should momentarily hold a long arc and thus increase the arc path and resistance. The minimum voltage values occur at the time of the globule transfer, and are of relatively short duration.

The average voltage shown while welding and maintaining the arc is called the ARC VOLTAGE (Figure 4.3). It is the amount of voltage required to overcome the resistance of the arc path. It is distinct from the open circuit or striking voltage. This latter is the voltage always available at the machine to strike and maintain the arc even though it may be unduly lengthened. If the arc is lengthened to such an extent that its resistance is greater than can be bridged by the open circuit voltage, the arc will be broken and extinguished. Arc voltage will depend on the length of the arc and the type of electrode and may be anything from 18 to 40 volts (Figure 4.4).

LOAD VOLTAGE is the voltage between welding machine terminals when the current is flowing. It is the true arc voltage plus losses in cables, connections, ground clamps, etc.

Some machines have a fixed open circuit voltage such as 70 volts, while with others it may be varied from around 60 to 90 volts. Sixty volts is considered the minimum open circuit voltage for DC machines and 65 to 80 for AC machines. A higher voltage makes for easier striking of the electrode but with AC it is usually considered that an undesirable danger of shock would exist above 80 volts. Therefore, in some machines,

to keep the open circuit voltage low and yet facilitate striking and to stabilize the arc, a small current of high frequency with great stability may be superimposed on the welding circuit. In others, a surge of voltage is brought into the circuit just momentarily when it is required.

It should be noted that adjustment of the open circuit voltage does not alter the arc voltage. The latter depends on the arc path resistance as determined by the type of electrode and the arc length as already noted above.

Machines that can vary both the current and the open circuit voltage are called "dual control" welding machines (see also Electrical Characteristics and Controls). Although a variation of open circuit voltage does not alter the arc voltage, it does determine to some extent the minimum and maximum current limits during welding. For instance, in the case previously cited, for a given electrode, where the average current of 130 amperes actually varies from 75 to 200, it is the open circuit voltage setting that largely determines these extremes, which are known as under-run and over-run. For some jobs little variation of these extremes is considered desirable, while for others, more is preferred. The choice, if any, is usually left to the operator.

It is well that students should also understand that the rate at which electrodes of a similar type are melted (and this largely determines the speed of welding) depends on the amount of current used and to no appreciable extent on either the arc voltage or the open circuit voltage.

Further, if 150 amperes is being used for a 5/32 in. diameter electrode and a change is made to a 3/16 in., no increase of speed results or, alternatively, if a 3/16 in. diameter electrode is being used at 150 amperes and a change is made to a 5/32 in. diameter at the same current, the rate of welding would remain the same. Larger electrodes will give faster welding only if larger currents are used with them.

From the foregoing it will be understood that a welding machine must provide the following three essential characteristics:

1. Current variable over a wide range.

2. An open circuit voltage sufficiently high to maintain an arc under varying conditions and to assist in striking the arc.

3. A quick response to the varying requirements of the arc for both voltage and current.

There is a wide variety of electrical means for obtaining these characteristics using either DC or AC. Different machines adopt different methods and the leading makes today are all highly refined products designed to accomplish these three essentials and other less important needs.

As Figure 4.5 shows, there are just four basic welding machine types:- A. Rotating - (1) Electric Motor and (2) Engine Driven welding machines and B. Transformer Type - (1) Transformer and (2) Transformer/Rectifier welding machines.

ROTATING TYPE DC POWER SOURCE

Until recent years DC rotating type generators were the principal power source for manual arc welding in America and most techniques and electrodes were accordingly developed for use with this type of current. Most present day welding generators are powered by an electric motor which is coupled to the generator on the same shaft (see Figures 4.6 and 4.7 - (a)) or alternatively - for field welding, the engine driven type is used. This is powered by an internal combustion engine and is not dependent on the availability of electric power lines (see Figures 4.8 and 4.9). Units in which the generator is driven directly by a motor are usually referred to as motor generator welding machines, or simply as MG sets.

For complete flexibility and a power source that will handle all manual operations with all electrodes and in all positions, DC is generally considered the best choice. The reasons may be briefly stated as follows:-

1. Most electrodes will operate on direct current but not necessarily on AC.

2. The polarity of DC may be changed to either negative or positive by the use of a reversing switch (see "polarity switch" in Figures 4.6 and 4.7).

3. Arc characteristics can be varied to a greater degree.

4. Output is not affected to the same extent by power line voltage variations.

5. DC is generally preferred by operators.

SINGLE OPERATOR DC VARIABLE VOLTAGE MOTOR GENERATOR SETS

The machines shown in Figures 4.6 to 4.9 inclusive, and others of the principal manufacturers conform, as a minimum, to the rating requirements of NEMA (National Electrical Manufacturers' Association) which are given in Table 4.1.

Power Supply

The power supplying the motor may be alternating current, normally 2 or 3 phase, mostly 60 cycle and 220, 440 or 550 volts. Less frequently the power supply may be direct current 115, 230 or 440 - 650 volts. The latter voltage is normally for trolley lines.

Nameplate

All standard makes of welding machines carry a nameplate. It is usually divided into three sections; one giving make and serial number, etc., and the other two pertaining to the motor and the generator.

Before connecting any machine to the power line, it is important to check the nameplate motor data to see that voltage, phase and cycle correspond to that available; also that the line is sufficiently large and

adequately fused to handle the input amperes.

Likewise, before using the machine, the operator should ascertain from the nameplate the generator capacity and its permissible duty cycle*.

In ordering parts, it is essential to give serial, specification and model number and desirable to include full nameplate data.

Electrical Characteristics. Controls.

The variable voltage MG set is provided with an adjustment of open circuit voltage to make possible a choice of different arc characteristics to match different types of jobs and welding conditions. The arc characteristics or "electric picture" of what happens at the welding terminals under various amperage and voltage conditions is illustrated by a static volt-ampere curve (see Figures 4.10 and 4.11). This type of 'drooping' characteristic means that with an increasing current output of the generator the voltage decreases and as the current decreases, the voltage increases.

These characteristics meet the requirements of the arc, as we have seen previously, because as the arc is lengthened, less current flows due to increased resistance. This in turn increases the voltage which serves to maintain the arc.

The drooping characteristic, or decrease of voltage from that of open circuit to just that required at the arc, is obtained by what is descriptively called a 'bucking' field. The welding current flows through this field and bucks or opposes the building up of voltage depending on its value. When no current flows, maximum or open circuit voltage is available. Thus it will be seen that the required voltage is inherently obtained as a result of the machine design.

Any number of volt-ampere curves can be produced for each open circuit voltage adjustment. In other words, the combination of two controls (Dual Control) allows the operator to blanket the entire range of the machine to choose a volt-ampere setting which can be anywhere or of any slope between the curve of the lowest open circuit voltage (Curve 1, Figure 4.12) and the minimum current, and that of the highest open circuit voltage and maximum current (Curve 2, Figure 4.12).

For example, a setting is chosen, say 140 amp. and 25 volts - point A in Figure 4.13. Through that point, any number of volt-amp. curves can be produced, varying in slope, as shown, from the gradually sloping curve 3 to the steep curve 4.

* Duty cycle or duty factor is the ratio of arc time to total time. A complete test cycle is 10 min. For a 60% duty cycle, load shall not be applied for more than 6 minutes out of any 10 minute period. If a power source is operated at a current greater than its rating, the duty cycle must be reduced. Or if the rated duty cycle is exceeded, the current output must be reduced to avoid overheating the welding machine.

When set for curve 4, a shortening of the arc, so that voltage drops to B, or 20 volts, causes little change in the welding current; the current increases only to 150 amp. This type of setting is more suitable for applications such as downhand or flat welding with large size electrodes.

For overhead welding in the Lincoln machine, for example, and others under different designations, the operator selects the range marked "overhead and vertical" (for "flat" welding, setting is "normal"). The overhead and vertical setting will give low open circuit voltage, with the current decreasing rapidly and less metal burning off the electrode when the arc is lengthened and the electrode is moved out of the puddle. The current will increase rapidly as the arc is shortened and the electrode is moved back in the puddle.

Figure 4.13 shows an explanation of these changes. When, for instance, the arc is shortened to B, or 20 volts, it is evident that this shortening gives a considerable increase in the welding current when set for curve 3. It makes the current 180 amp. Hence, this setting gives a 'digging' arc - one that is more suitable for overhead or vertical welding.

It should now be clear how the dual control works. One control is to vary the open circuit voltage, or the arc characteristics of the welding machine, and the other is to vary the current for different sizes of electrodes. By continuous ranges of both controls, it is possible to completely eliminate any blind spots.

If the operator is working in the flat position exclusively, on one type of metal, he may need to use only the current control, i.e. 'single' instead of 'dual' control. Indeed a number of makes feature "Single Control', which is to say that the desired output of the machine may be had by adjusting only one control dial. On these machines the electrical circuit is designed to provide a compromise arc characteristic which may be also considered quite satisfactory for welding in all positions with all diameters of electrodes within the range of the machine.

Terminals

The welding circuit of the generator ends in two terminals; one for the electrode cable, and the other for the ground cable. These terminals may be designated 'Electrode' and 'Ground' or 'Positive' and 'Negative', or 'Reversed' and 'Straight'. In most, but not all machines, the terminal marked 'electrode' is positive.

No Voltage Protection

Most electric motor-driven machines include in their controls a suitable starting switch for the electric motor equipped with "overload" and "no voltage" protection. "No voltage" protection means that the machine will not start, after power failure, until the "start" button is pressed. Without "no voltage" protection the machine could start again when the power returns and if the electrode holder were accidently left in contact with the work, arcing might occur, causing a fire or a machine burned out from overload. Transformers are not normally equipped with such protection.

Power Leads

The power leads chosen to connect the welding machine to the line must be adequate in cross-section as prescribed by electrical codes. In the case of 3-phase machines, a 4-conductor power lead must be used, in which case the fourth lead (usually marked green) is connected to the ground of the disconnect switch on one end and to the frame of the welding machine on the other. (The grounding of electrical equipment is a code requirement). It might well be mentioned here that the size of conductor for the connection of a welding machine is very important, and if too small a conductor is employed, the overload protection switch may trip frequently or fuses in the disconnect switch may be blown, as the machine will draw a higher current than normally because of the voltage drop through the restricted supply line.

Adjustment of Welding Machine Controls

As there are a number of welding machines commonly employed, each having a somewhat different method of current and voltage regulation, it is desirable that the student be familiar with representative types in order to make the necessary control panel adjustments to obtain the desired values and best operating performance.

To this end, illustrations of a number of typical control panels are included herewith.

Lincoln "Shielded-Arc" Dual Control MG Welding Machine

The principle of dual continuous control, as well as the arc characteristics of this type of machine have already been detailed above (see also Figures 4.6 and 4.10 to 13).

The left hand control varies the voltage and is termed a "job selector". It is a shunt field-rheostat or voltage regulator.

Polarity is changed by the center control lever: "Electrode Positive" - means reverse polarity and "Electrode Negative" - means straight polarity. The "off" position, shown also in the center control (see detail in Figure 4.6(a)), shuts off the welding current but does not stop or disconnect the machine from the power supply.

Hobart MG Welding Machine

Figure 4.7 - a, b and c illustrate the details of this type of machine having similar characteristics and controls to those of the Lincoln. Both controls No. 3 and No. 4 (Figure 4.7 - a and b) may be adjusted separately and any combination of the two can be obtained.

General Electric MG Welding Machine

Figure 4.14 shows the control panel of a General Electric Model 6WD40AE welding machine. Six main current taps are available corresponding to the approximate current values for different electrode sizes. The left hand control gives finer adjustment to select the precise value desired. For example, with the electrode selector switch at the 3/16 in.

setting the current can be adjusted from 140 to 250 amp., or that is, a range suitable for a 3/16 in. diameter electrode.

The polarity switch is on the left. Stop-start push buttons are on the far left (not shown).

P and H (Harnischfeger Corporation) MG Welding Machine (Types W - 300 - MG and W - 400 - MG)

Figure 4.15 shows the control panels of the Harnischfeger machine. One control with indicator is used to choose the proper electrode size (six in all), the other to set the exact current needed. Voltage adjusts automatically.

Airco - 200 amp. Wasp MG Welding Machine

Here (Figure 4.16) the main current adjustments are obtained by a "gear shift" or tap arrangement - "Min", "Med" and "Max" (left hand top). A fine adjustment of current for each of these taps is possible through the control in the middle. Each setting overlaps the other somewhat so that no gaps exist.

Positive and negative electrode terminals are shown at the right of the panel.

ENGINE DRIVEN SINGLE OPERATOR DC WELDING UNITS (see Figures 4.8, 4.9 and 4.17)

In places where no electric power is available, gasoline or diesel engine-powered welding machines are the only choice.

The gasoline engine-driven unit is essentially the same as the electric motor driven single-operator welding machine, but instead of the electric motor, a gasoline or diesel engine is coupled to the welding generator. Ratings are the same as shown in Table 4.1.

Idling Device

In order to effect greater operating efficiency, gasoline driven units are equipped with idling devices. The purpose of the idling device is to reduce the revolutions of the engine to approximately one-half the operating speed when the arc is broken. The instant an arc has been struck and welding begins, the device automatically opens the throttle of the engine to full operating speed. Most idling devices utilize the vacuum of the intake manifold of the gasoline engine to close the throttle and the current surge of the welding circuit when striking an arc to open the throttle. The advantages of an idling device are savings in fuel and reduced wear and tear on the engine.

Governors

For satisfactory welding operation it is essential to keep the welding current steady. To accomplish this the engine must operate at a reasonably constant speed at all loads and must therefore be equipped with a governor. This governor opens and closes the engine throttle and will

maintain constant engine speed within approximately 5%. Such a variation in speed is far less than can be expected of an electric motor driven welding machine, the speed of which may change considerably more, depending upon the fluctuations of the line voltage.

Filters

To protect the moving parts in the interior of the engine, fuel, air and lubricants must be filtered efficiently.

Oil Changes

An engine operating at 1800 RPM would drive most makes of cars approximately 36 miles in one hour and it would take approximately 28 hours at that rate of speed to cover 1000 miles. Just as a car requires frequent oil changes in its engine, so does the industrial engine driving the welding generator. Usually the manufacturer's recommendation for an engine equipped with an efficient oil filter calls for an oil change for every 50 hours operation.

Auxiliary Power

Auxiliary power, DC or AC, 110 or 220 volt is frequently incorporated in the machine as an additional supply for lights and tools needed in the field. The overall power requirements determine the amount of auxiliary power needed for the job. One to ten KW can be made available depending on the make.

SINGLE OPERATOR TRANSFORMER TYPE AC WELDING MACHINE

The single operator transformer is the simplest and most efficient unit for supplying current suitable for arc welding. Whereas the motor-generator set takes power from the line to drive a motor which in turn drives a generator, the transformer directly converts the current of the power lines for welding purposes.

Such a transformer consists of a laminated iron core on which are wound a large number of wire turns known as the primary winding, together with a fewer number of turns of a heavier wire known as the secondary (see Figure 4.18). Such an arrangement will take high voltage, low amperage current from the power lines to the primary winding and it may be drawn out as low voltage high amperage current from the secondary side for welding. The voltage on the secondary side will be the striking voltage. To adjust the current, stabilize the arc, and to reduce the open circuit voltage to the arc voltage, a reactance is developed in the circuit. For this purpose a separate reactor may be used consisting of an iron core about which wire turns are wound and it may be adjusted by moving the iron core in and out of the windings (see Figure 4.18).

In another type where the current controlling reactance is integral with the transformer, adjustment may be made by moving the secondary coil with relation to the primary or by varying the magnetic path of the transformer core. This latter is accomplished by moving an iron mass within a magnetic gap in the core itself. These adjustments are made by a crank and screw mechanism common to most transformers (see Figures

4.18 and 4.19). Figure 4.20 shows the interior of a transformer with a movable coil.

Another form of control uses a simple rheostat to vary a small DC current by which the reactor is saturated. This DC is obtained from a small separate DC rectifier incorporated in the machine. Such a control is shown in Figure 4.21. In this particular illustration it adjusts the transformer of a rectifier welding machine but the principle is the same.

Reactor controls waste power but the overall loss is not as great as with motor-generator sets in which losses occur in both the motor and the generator and consequently the AC transformer is a more efficient unit than the MG set. Further, it does not consume as much power during idling periods, when the operator is not actually welding.

It does however have a lower power factor* under load and for this the electrical supply companies usually exact an additional charge. This condition can, to a considerable extent, be remedied by the use of capacitors and these are now incorporated in most AC machines.

Another loss may be incurred with AC transformers if the electrode and ground leads are wound around, or lie about in close proximity to, large masses of metal - such as the object being welded, or a metal slab or floor. In effect a reactor is produced which will lower the current just as in the transformer itself.

AC welding leads should be kept taped together for as much of their length as possible and where they are necessarily separated towards the ends, care should be exercised that only a minimum of metal lies between them.

An inherent advantage of the AC transformer is its simplicity and absence of rotating parts. This reduces the maintenance costs. Another advantage is the almost entire absence of arc blow in welding. Arc blow is an electrical phenomenon which, due to magnetism in the work caused by the welding current, will blow the arc in one direction or another making good welding difficult. One of the easiest ways to reduce it is to lower the welding current. This, however, lowers the rate of welding. Arc blow is largely absent with AC and higher welding currents may be employed under those conditions where arc blow would normally occur. In such cases the use of AC speeds welding and reduces costs in comparison with DC.

The ratings of standard AC transformers under NEMA standards are as shown in Table 4.2.

The student should also be aware that there is a range of small transformers known as "limited input" welding machines. These have a smaller current range and a lower duty cycle as shown in Table 4.3. They are designed primarily for rural communities or locations where the power circuit is inadequate to handle larger machines. If used for industrial purposes, their limitations should be appreciated and care observed.

* Power factor is a ratio of true watts to apparent watts. Welding transformers are inherently low power factor devices. That is they use more power than is normally metered.

Despite the advantages enumerated above, most operators still prefer DC which they find easier to handle and with arc characteristics more to their liking.

However, AC welding is at present gaining considerable ground due especially to cost factors, and to the absence of arc blow. It waited on the development of suitable coated electrodes. Such electrodes are not yet generally available for some special applications and particularly for the welding of non-ferrous metals. With the advent of such electrodes its field of application will further increase. Today it is mostly used in industry for the production welding of heavy steel fabrications. Also many small units, because of their cheapness, are sold to garages, job shops and farmers.

DC RECTIFIER TYPE WELDING MACHINES

A machine which combines some of the major advantages of both the DC motor-generator set and the AC transformer is the DC rectifier type. It has been developed in recent years and now has wide acceptance.

Basically, it is a three-phase AC transformer welding machine to which has been added a selenium type rectifier. This latter changes AC to DC and is of a simple robust construction, as will be noted from Figures 4.21 and 4.22. The selenium rectifier consists of a sandwich composed of steel plates and microscopically thin layers of selenium (No. 4, Fig. 4.22). It does not add appreciably to the maintenance of the machine. A more recent development is the use of a silicon or germanium rectifier.

Portable, engine drive, rectified DC welding machines may use an alternator to generate the electrical energy and a rectifier to convert the AC to DC. This design eliminates the commutator and brushes of the wound DC generator.

The methods of current control used by different manufacturers in rectifier machines are as varied as the methods of current control in single-phase, AC transformer welding machines. The moving coil transformer, movable core reactor, saturable reactor and magnetic leakage control methods are all represented among the commercial designs.

The current output of all rectifier-type DC welding machines is controlled on the AC or input side to the rectifier, with the exception of some special-purpose machines with very low output. NEMA ratings for DC rectifier-type welding machines are shown in Table 4.4.

Rectifier-type machines may be divided broadly into two general types, in accordance with their volt-ampere curves and their application. Machines, the volt-ampere curves of which show an appreciable droop, are generally most suitable for single operator manual welding applications. Welding machines exhibiting this characteristic are often referred to as CONSTANT-CURRENT devices. This reference results from the fact that the welding current remains fairly constant for small variations of arc length. A constant current welding machine, when adjusted for rated output, should maintain the current within 5% of the rated value, with a variation in arc voltage 10% above or below normal arc voltage.

The other general type is the so-called CONSTANT-POTENTIAL machine which is designed specially to power the various automatic and semi-automatic welding processes which use as the electrode a continuous length of wire fed at a constant rate. Voltage drop is comparatively small - approximately 1 volt with every hundred amperes. In other words, changes in current have little effect on the arc voltage. Figure 4.23 shows a comparison of curves for variable voltage output, i.e., conventional drooping curves as those shown in Figures 4.10 to 4.13 inclusive, and for constant voltage output.

The rectifier welding machine has somewhat lower efficiency than the usual AC transformer and care must be taken to ensure that it is kept free of dust and is not overloaded. It does not eliminate arc blow.

AIRCO Selenium Rectifier DC Welding Machine

The Airco rectifier of the Bumblebee series is illustrated in Figure 4.22. Three separate current ranges are provided by the switch in the control panel. A micrometer rheostat provides for precise current adjustment within each range. Current ranges are calibrated in amperes.

WESTINGHOUSE Rectifier DC Welding Machine - Type RA

The Westinghouse Type RA rectifier welding machine is designed to operate from three-phase alternating current and to deliver direct current to the welding arc. It consists essentially of a combination three-phase transformer and moving core reactor designated as a "Transactor Unit". This serves both as a transformer and as a reactor to control the welding current. The machine is supplied with either a selenium or silicon rectifier. These machines have an auxiliary feature known as the "Arc Drive Control", which enables the operator to adjust the machine's transient characteristics to suit the particular welding job. The machine is illustrated in Figure 4.24.

COMBINATION AC - DC WELDING MACHINES

A further development has been to combine an AC Transformer Welding Machine with a Rectifier with controls so arranged that it can be used for either AC or DC welding. This makes it possible to use whichever type of current is best suited to a given application without the added cost of duplicate equipment. A typical machine is illustrated in Figures 4.25 and 4.26. Such machines are made by Lincoln and Miller and others.

This type is essentially a true AC (single-phase) welding machine with a rectifier attached, and it is becoming popular. The operator has the choice of alternating current or straight or reverse polarity direct current, simply by throwing a switch to one of three positions. The machine can be used in locations where only single-phase power is available and occupies less floor space. A unique system of controls enables these machines to be utilized for the following seven different types of welding applications:

AC and DC Manual Metal Arc Welding

AC and DC Manual Inert Gas Welding

ARC WELDING EQUIPMENT

AC and DC Automatic Inert Gas Welding

DC Inert Gas Spot Welding

PARALLEL OPERATION OF WELDING MACHINES

A. - DC Motor-Generator Sets

It is occasionally found desirable to operate two machines together in order to obtain a higher welding current than is possible from one only.

This can be done very simply with most machines of the same make. Different makes, types and sizes can be combined, but this involves added complications and precautions, and is not recommended except under necessity and with expert guidance.

In combining machines of the same make, size and type it is advisable to observe the conditions given herewith even though all may not be necessary in each case. (Also, in some instances similar precautions may be taken in different ways. To avoid possible confusion they are not given here and any simplification or short cuts should be taken only on expert advice.)

To combine for greater output, i.e. to parallel the machines, take the following steps in the following order:

1. Start all sets (more than 2 may be combined if desired).
2. Adjust sets so that the open circuit voltage is the same for all. If there is no voltmeter, set voltage rheostats to the same positions.
3. Adjust current controls to approximately the same value so that each machine shares the load equally.
4. Connect the electrode leads or terminals of each set together and also the ground leads or terminals. Be sure that each is of the same polarity and that the machines are up to speed before making the connections.

The rheostats changing open circuit voltage should not be altered while the sets are running in parallel. The paralleling connections should be broken before performing this operation. If an adjustment is made it should be the same for each.

Current adjustments may be made while the machines are connected in parallel and the same change is advisable for each.

The paralleling connections should be broken before the machines are stopped and they should be started before being paralleled again.

It is highly undesirable that one machine should stop while the other is running. This can happen if one machine is tripped off the line by the action of its overload or no voltage protection devices. It is therefore recommended that the motor starters of each unit be connected in series so

that if one goes out the other will do likewise.

Sometimes it is desirable to make a permanent paralleling installation whereby two machines may be combined as one, or used separately, by simply operating a switch. Such a set is shown in Figure 4.27.

An equalizer connection is shown going to the lower right hand brush holder in each case. Such an equalizer connection is usually desirable and its installation warranted in the case of permanent connections. Connecting or disconnecting the two machines for operation together or separately is quite easily effected by the three-pole switch shown.

The stacking of two machines to save space is shown in Figure 4.28. These machines can also be readily connected for parallel operation and controlled by individual rheostats. If more than three machines of this type are paralleled, a separate source of excitation is required, such as a small DC welding set or a suitable DC shop power line.

Where a permanent connection of any machines is considered warranted, it is suggested that the manufacturer be consulted. This is good policy in any case except when an emergency does not permit.

B. - AC Transformer Type Welding Machines

Single operator, AC welding machines which have the same no-load voltage (secondary open circuit voltage rating) may be operated satisfactorily in parallel in order to get more current per arc than either machine will provide separately. When two transformers are connected together, care must be taken to connect both on the primary side to the same phase of the same power supply. This is checked, before the electrode leads B in Figure 4.29 are connected together, by measuring the voltage between them after the primary windings are energized. The voltage reading should be close to zero. If it is double normal voltage, the polarities of the machines are opposite and the primary connection must be reversed and checked again.

If the transformers which are paralleled have condensers for power factor correction, one should never be connected to the power circuit without the other. They should be connected and disconnected from the power line simultaneously through a common switch controlling the power to both, or their paralleled connection must be broken before taking them off the line separately.

MULTIPLE-OPERATOR WELDING EQUIPMENT

Where there is a concentration of welding machines in a small area, as is frequently encountered in shipbuilding, multiple-operator equipment has proved economical with regard to cost of installation and operation.

Assume a certain small area in which there are 100 welding machines, each operating at 200 amp. per arc about 25% of the time. Where single-operator units are employed, the usual practice is to install a 200 or 300 amp. single-operator welding machine for each operator. A total installed capacity of 20,000 or 30,000 amp. is therefore required. A multiple-operator system, however, requires only 5000 amperes in gener-

ating capacity to handle the load, because each operator, working at 200 amp. needs this current for only one-quarter of the time. Thus 50 amp. is the effective load of each welding unit.

In large installations multiple-operator equipment usually results in a reduction of the fixed cost of equipment and cable, the amount of power used and maintenance. The individual resistor or reactor current control panels (see Figures 4.31 and 4.32) can usually be located close to the operator to enable him to make current adjustments conveniently. With DC all operators must weld with the same polarity, since individual circuits cannot conveniently be reversed. Although most installations are DC, - either MG units or static rectifiers - some shipyards have used transformer AC multiple-operator apparatus. Commercially available units vary from 600 to 2500 amp. for rotating machines; from 500 to 1500 amp. for rectifier-type installations, and from 500 to 2000 amp. for transformers. Rectifiers used in these power supplies are selenium, germanium or silicon types. Overload protection and circuit breakers protect the equipment from damage.

Usual practice is to provide a power source voltage of 70 to 80 with provision for paralleling two or more units for combined output. The manufacturer's instructions should be followed to ensure proper parallel operation.

Figure 4.33 shows a typical multiple-operator welding installation comprising two paralleled power sources (say two 1500 amp. constant potential rectifiers like that shown in Figure 4.30) and resistor grids (Figures 4.31 and 4.32). Large copper busses are run from the power source to the distributor panels and the individual resistor grids. As many as six to ten circuits may be grouped in one panel (Figure 4.32). The resistor for DC (or reactor for AC) is adjustable in order that the amount of welding current it passes can be controlled.

MAINTENANCE OF EQUIPMENT

Arc welding machines perform essential functions in the production set-up of many manufacturing organizations, and should therefore be subjected to the same careful maintenance as machine tools, by means of rigid periodic inspection schedules. Such schedules have superseded the obsolete practice of keeping the machines going until breakdown. In fact, if followed, they will tend to keep all arc welding machines in continuous operation. Although intricate repairs and adjustments should always be performed by qualified electricians, it is important that a conscientious operator and especially a supervisor should have a basic knowledge of maintenance jobs in order to carry out emergency repairs when no electrician is available.

Proper maintenance begins with the installation of the machine, e.g., it should be installed where cool clean air can circulate freely, and never in a closed recess which may be heated by the sun, forge fire or any other external source of heat. It should also be placed at sufficient distance from the work to avoid contact with arc spatter and fumes. Moreover, the equipment should be safe from mechanical and atmospheric damage such as may be caused by loading equipment and severe weather conditions. Since workshop floors are seldom entirely clean, it is bad practice to install the

machine on the floor, an elevated position being generally recommended.

A very common trouble encountered in welding machines, which can impair the work appreciably is a variation in welding current, or as the operators describe it, "the machine running hot" or "cold".

Before attempting to determine the cause of the trouble in the electrical or mechanical part of the machine, the operator is well advised to check cables and connections in the following manner:-

1. Check the complete welding circuit for cable breaks.

2. Check the circuit for shorts.

3. See if lugs and bolts are tight. Eliminate as far as possible the use of hand actuated wing nuts: a wrench should be used to give tight connections.

4. Investigate if contact parts are broken, corroded or covered with dirt and rust.

5. Check ground clamps for proper contact, especially when doing heavy work.

TRANSFORMER MAINTENANCE

The use of AC transformers is often preferred because of the low maintenance cost owing to the absence of moving parts in the main mechanism. This simplicity, however, sometimes results in lax transformer inspection methods. It is important that current regulators be lubricated periodically, using a high melting point grease; this is particularly important in the case of motor-operated controls which should be lubricated about three times during the year. At the same time, windings should be cleaned out with compressed air, especially in workshops where dusty conditions are prevalent; further, connections and coil supports should be tightened.

RECTIFIER MAINTENANCE

In addition to the precautions to be observed with transformer type welding machines, the selenium (or silicon, or germanium) stacks of rectifier machines should be kept as free of dust as possible by placing the machine in as dust free a position as practicable and by periodic cleaning of the stacks.

MOTOR-GENERATOR MAINTENANCE

Bearings should be lubricated with a grease of a consistency suitable for the specific type of bearing. This should be carried out so that old grease and excess dirt is exuded as much as possible, and occasionally a grease solvent should be used for cleaning the bearings. The cleaning method depends upon the type of bearing and is relatively easy when the used grease can be removed through a relief plug. The lubrication instructions accompanying the machine should be followed and care should be taken not to over-grease the bearings as this may result in undue heating.

Dust and dirt accumulating in the welding generator as well as the motor windings should be blown out with a low pressure air hose, taking care that dirt is not blown into the insulation. Air suction is therefore a better method of cleaning the windings, especially in workshops where abrasive dust is present. The frequency of this operation will depend upon the extent to which the machine is used as well as the type of dust present. It is difficult to make a general rule since experience should govern the frequency of cleaning. Frequent and careful cleaning is advisable in workshops where the dust is conductive, i.e. the dust contains metallic substances.

Another frequent cause of trouble is dirty commutators. These should be checked periodically and, when necessary, cleaned out with fine sand paper, not emery cloth or dirty rags. The commutators may have to be turned down on a lathe when they reveal uneven wear which may become apparent by excessive sparking.

Regular brush inspection is particularly important as the brushes are subject to constant wear. They should be replaced and fitted to the commutators well before they are worn to the rat-tail connector.

Contact parts, especially magnetic starters, should be kept free from dust and dirt, and pitted surfaces should be cleaned.

As general guidance, an inspection of the machinery as outlined above should be carried out about once a week to once a month. In addition, motors and generators in constant use will require a complete overhaul once a year, a job which should be performed by qualified electricians. Properly scheduled maintenance will result in a reduction of maintenance cost and will avoid costly production stoppages. Maintenance should not be left until a fault becomes apparent, but should be done periodically, and a record should be kept of the inspection. Further, sufficient spare parts and, where many identical machines are used in one organization, sub-assemblies such as rheostats should be stocked so that shut downs will be avoided.

It should be borne in mind that prevention is the best means of maintenance. Although workshops may appear clean, the maintenance record may reveal that dust and dirt is the cause for many unnecessary maintenance jobs. The installation of dust inhibitors on the welding machine such as spun glass pads and filters may be economical in the long run. Where filters are installed they should be cleaned more frequently than the machine.

Manufacturer's maintenance and trouble shooting instructions are usually delivered with the equipment. They should always be followed carefully.

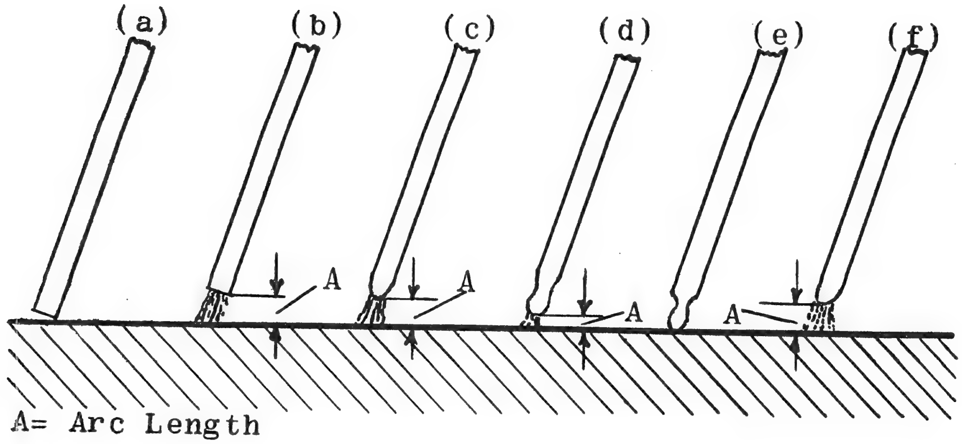


Fig. 4.1
Arc Formation with Bare Electrodes

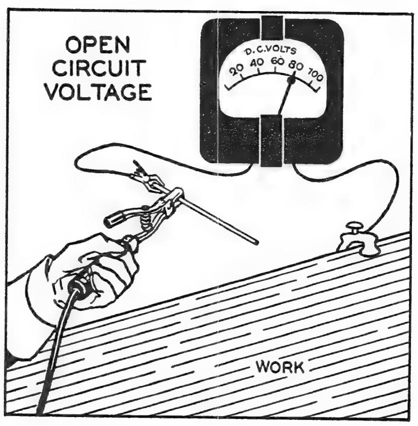


Fig. 4.2

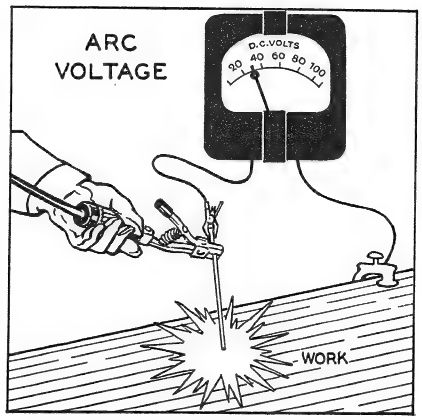


Fig. 4.3

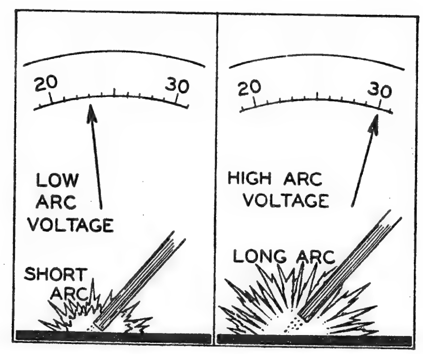
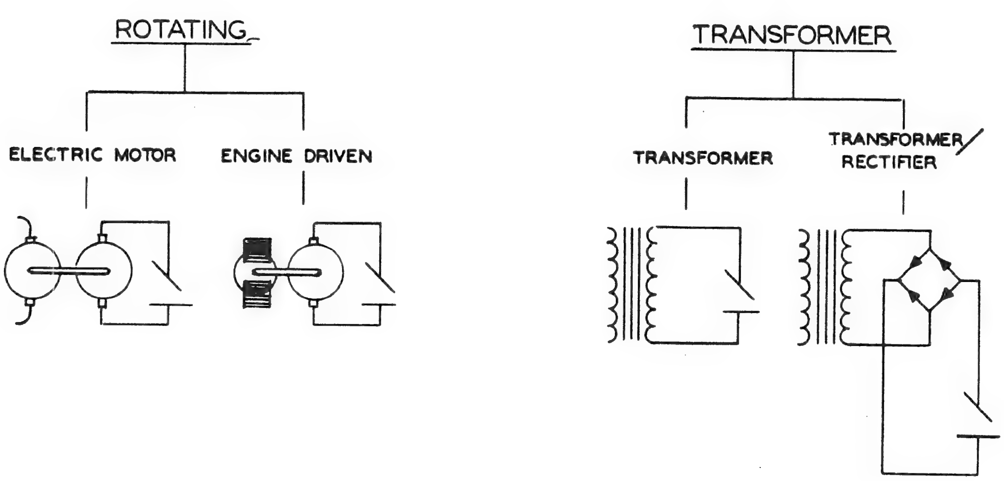


Fig. 4.4



A

B

Fig. 4.5
Four Basic Welding Machine Types

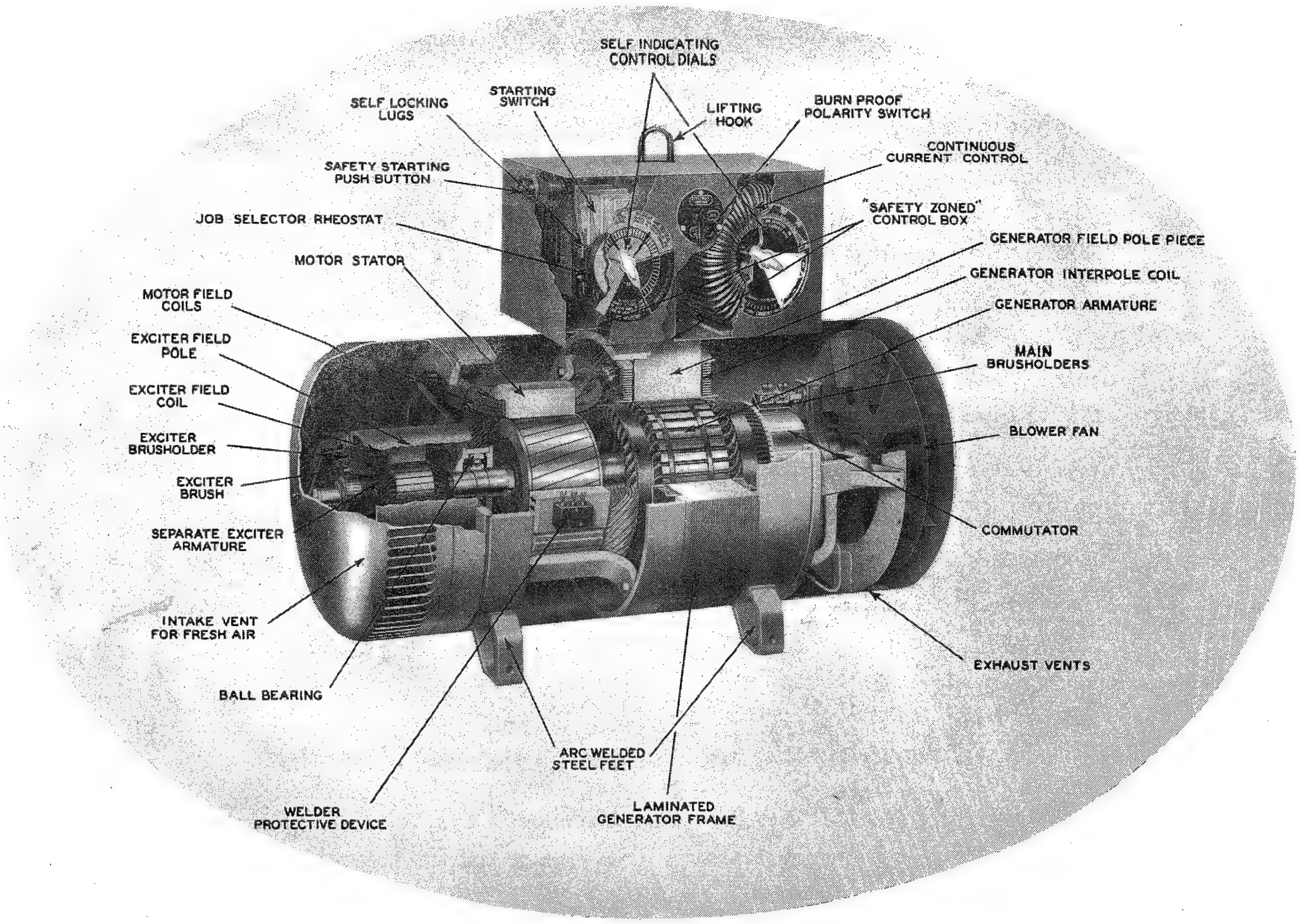


Fig. 4.6
Lincoln "Shielded Arc" Dual Control DC MG Welding Machine

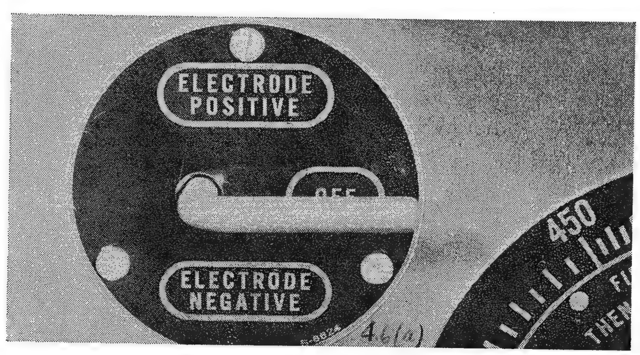


Fig. 4.6 (a)
Polarity Switch

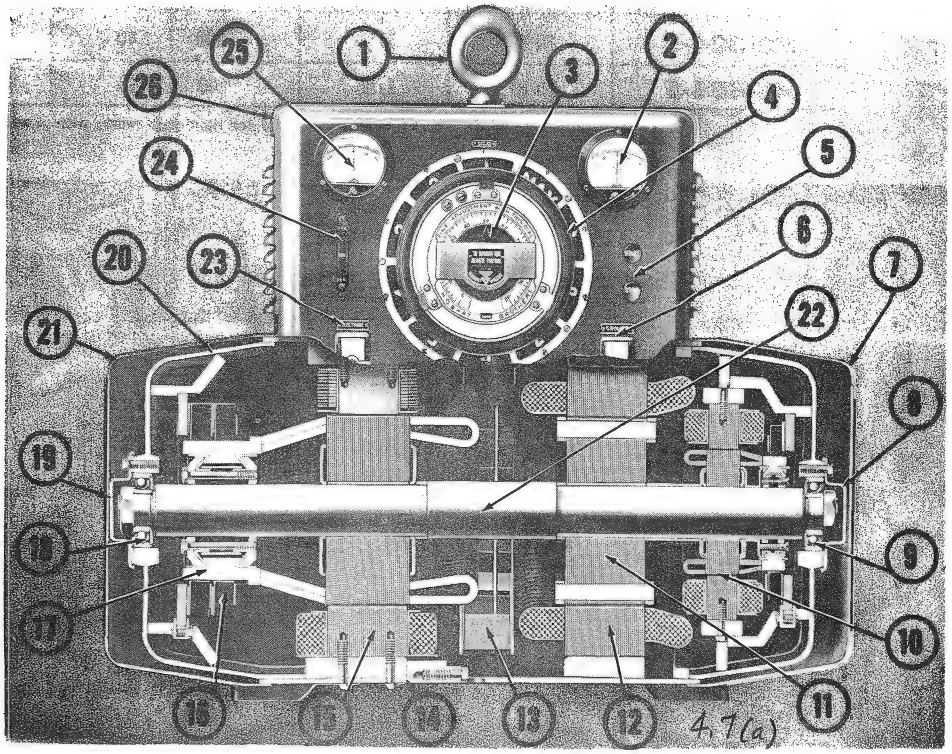


Fig. 4.7 (a)
Hobart DC MG Welding Machine
1. Steel lifting eye - 2. Voltmeter - 3. Inner wheel and dial for adjustment of heat and of relation between voltage and current - 4. Outer wheel and dial for selecting desired welding range - 5. Starting switch - 6. Ground cable connector - 7. Removable steel covers - 8. Pressed steel bearing cap - 9. Ball bearings - 10. Four-pole exciter - 11. Arc welded copper squirrel cage rotor - 12. Motor stator - 13. Heavy steel fan - 14. Steel frame - 15. Four-pole "Multi-range" generator - 16. Metallic graphite brushes - 17. Commutator - 18. Ball bearings - 19. Pressed steel bearing cap - 20. Arc welded steel frame - 21. Removable steel covers - 22. Single unit steel shaft - 23. Welding cable connector - 24. Polarity switch - 25. Ammeter - 26. Steel turret top with removable cover.

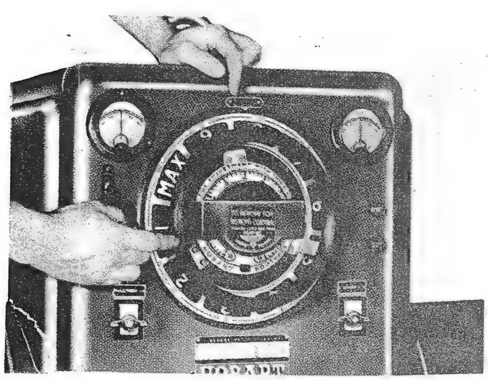


Fig. 4.7 (b)
Dual Control of Hobart Machine: The large range wheel on the front and volt-amp. adjuster inside the wheel give the operator specific adjustments for any job.

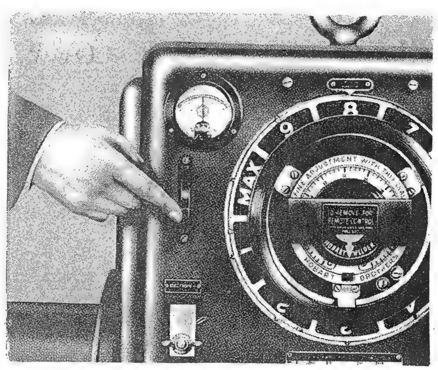
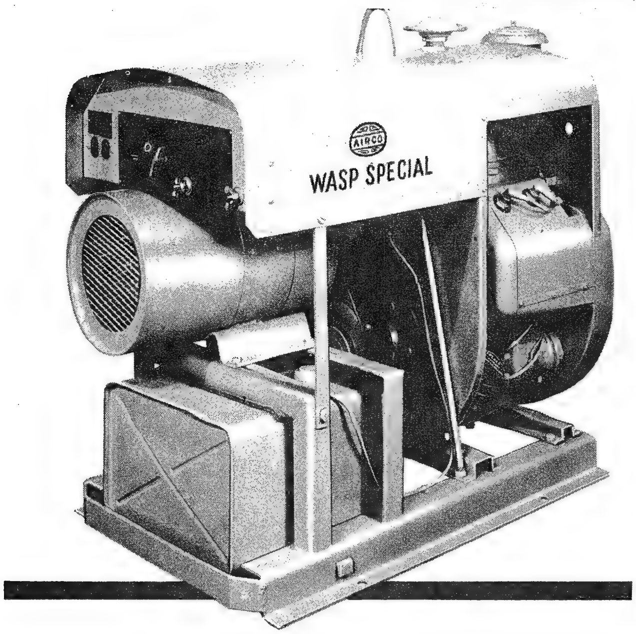


Fig. 4.7 (c)
Polarity Switch enables the operator to change the polarity instantly. It is located in exciter circuit.



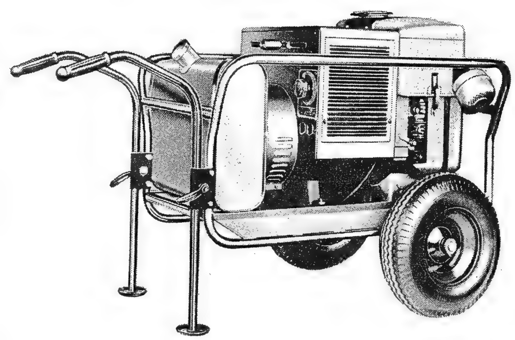


Fig. 4.9
"Sureweld" Model SGW 200P Engine-Driven Welding Machine

Fig. 4.8 - left
200 ampere DC Engine-Driven "Wasp Special" Welding Machine

ENGINE DRIVEN TYPE OF DC WELDING MACHINES FOR FIELD WELDING

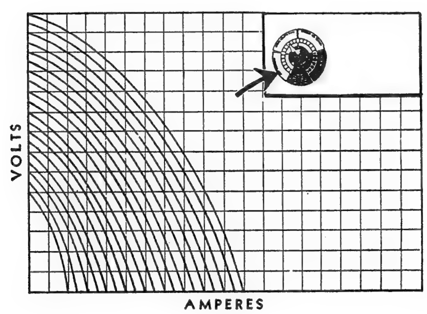


Fig. 4.10
Change of open circuit voltage produces a series of volt-amp. curves of similar characteristics or slope.

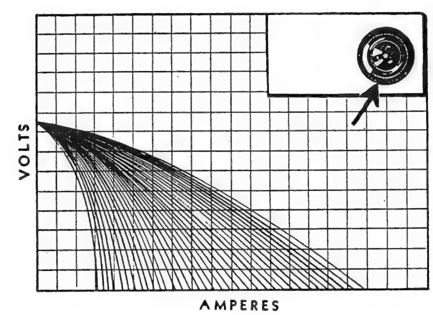


Fig. 4.11
Change of current with fixed open circuit voltage produces a series of volt-amp. curves of different characteristics or slope.

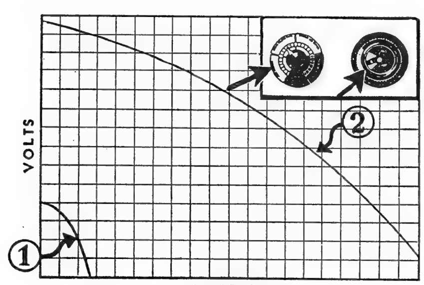


Fig. 4.12
Combination of two controls enables the operator to blanket the entire range of the machine to choose any volt-amp. setting between the curve of the lowest and the highest open circuit voltage and minimum and maximum current.

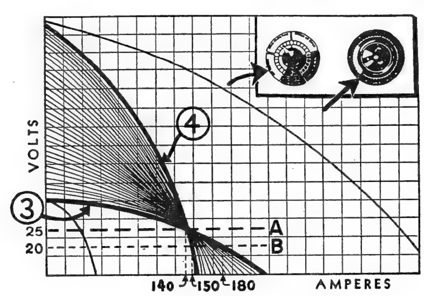


Fig. 4.13
Curves 3 and 4 each give an average of 140 amps. at an average arc voltage of 25 but the over-run of 3 is much greater, giving a digging or penetrating effect.

ELECTRICAL CHARACTERISTICS AND CONTROLS FOR THE VARIABLE VOLTAGE DC MG SETS.

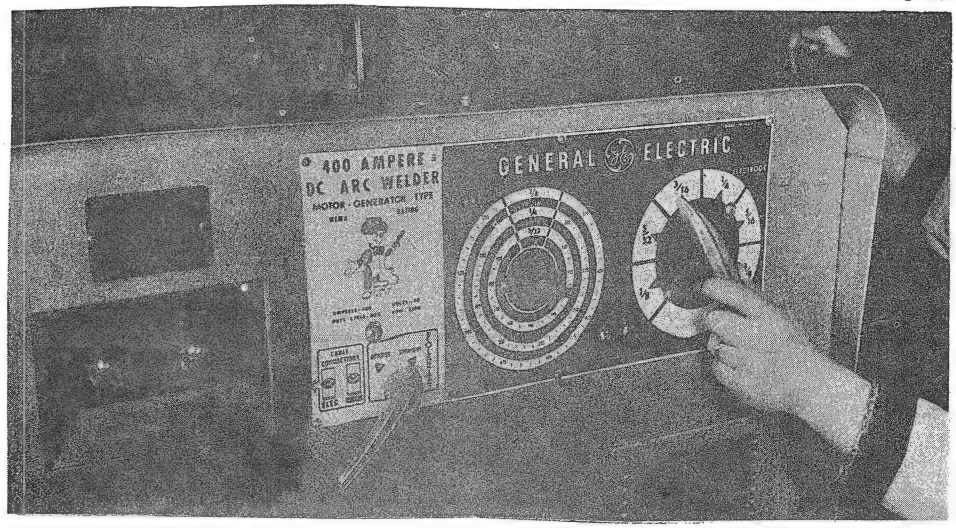
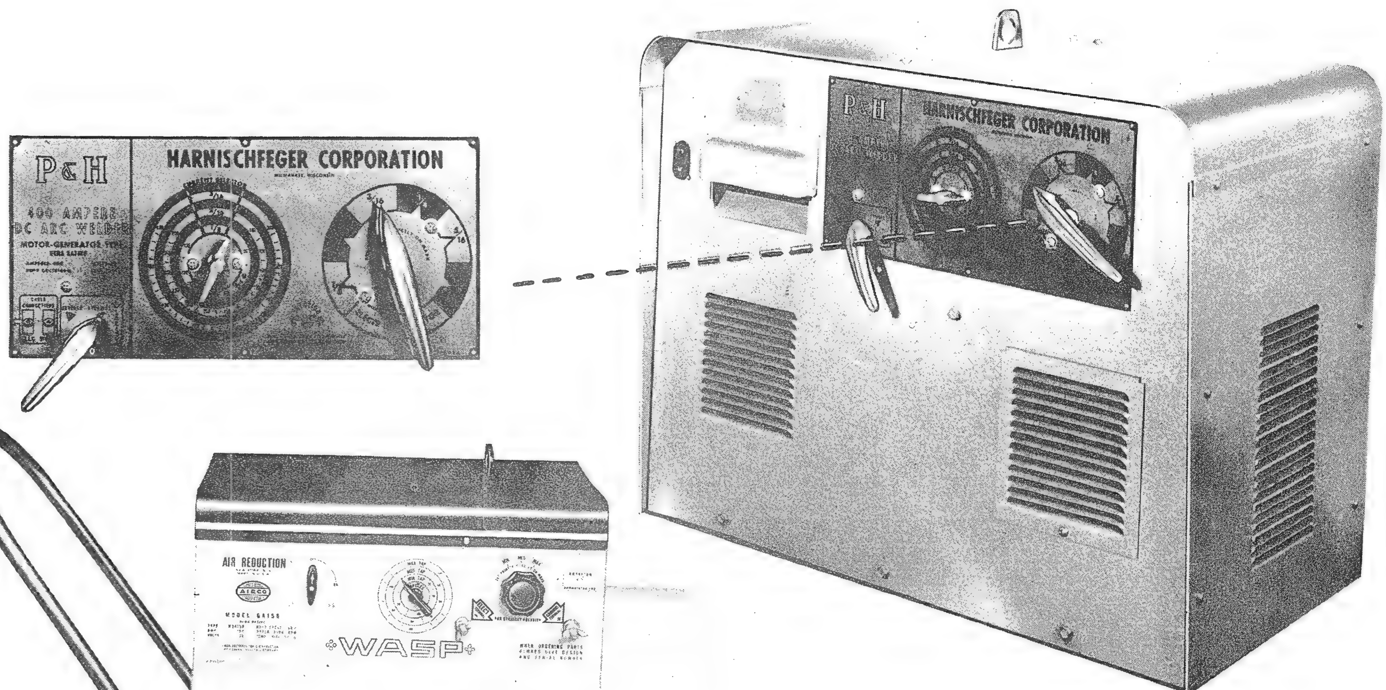


Fig. 4.14
General Electric DC MG Welding Machine
Six main current taps are here available corresponding to the approximate current values for different electrode sizes. The left hand control gives finer adjustment to select the precise value desired.



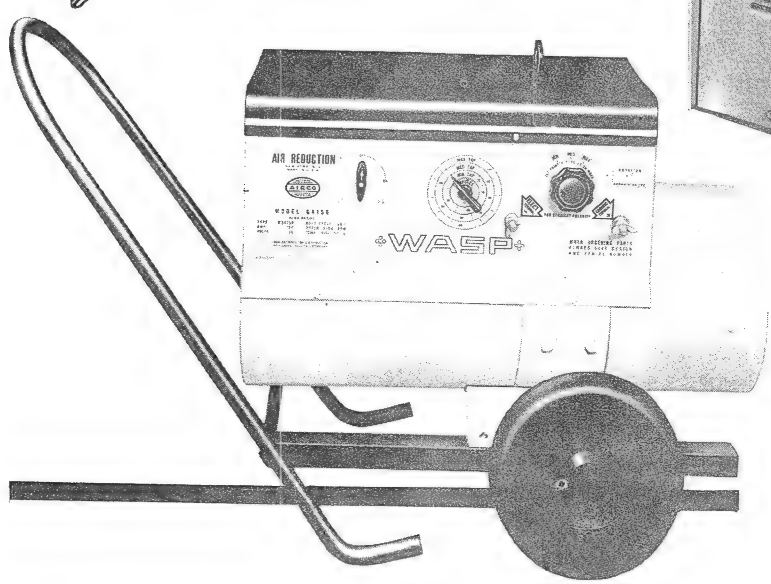


Fig. 4.15
P and H (Harnischfeger Corporation)
DC MG Welding Machine
The control panel arrangement is somewhat similar to that shown in Fig. 4.14.

Fig. 4.16
AIRCO - 200 amp. "Wasp" DC MG Welding Machine
The main current adjustments are obtained by a "gear shift" or tap arrangement. Fine adjustment of current is obtained from the middle control.

ARC WELDING EQUIPMENT

GENERATOR

TYPE	WNG-300	WNG-400
Rating-NEMA		
Amperes	300	400
Volts	40	40
Duty Cycles	60%	60%
Speed	2150 rpm	2150 rpm
Temp. Rise	50° C	50° C
Welding Range		
Min amp at 20V	60	80
Max amp at 40V	375	500
Max open circuit Voltage	80	80

ENGINE

Type	Hercules JX4
Horsepower	54 at 2,150 rpm
Oil Capacity	6 qts. (incl. filter)
Starting	Electric
Governor	Hoof gear-driven
Oil Filter	Fram
Air Cleaner	Vortex (oil-bath type)
Oil pressure gage	Direct reading

ASSEMBLY

Base	Steel fabricated, full-length skid-type
Canopy	Full-length, 16-gage steel
Side panels	16-gage, can be locked
Fuel Capacity	25 gallons
Cooling system capacity	14 quarts
Slowdown control	Electric—10 seconds time delay, or vacuum variable time delay

Weight (dry)	
300 amp rating	1,615 lbs.
400 amp rating	1,625 lbs.
Dimensions	
Height	46¼ inches
Length	64 inches
Width	27½ inches

Fig. 4.17
Typical Specification of an Engine-Driven Single Operator DC Welding Machine.

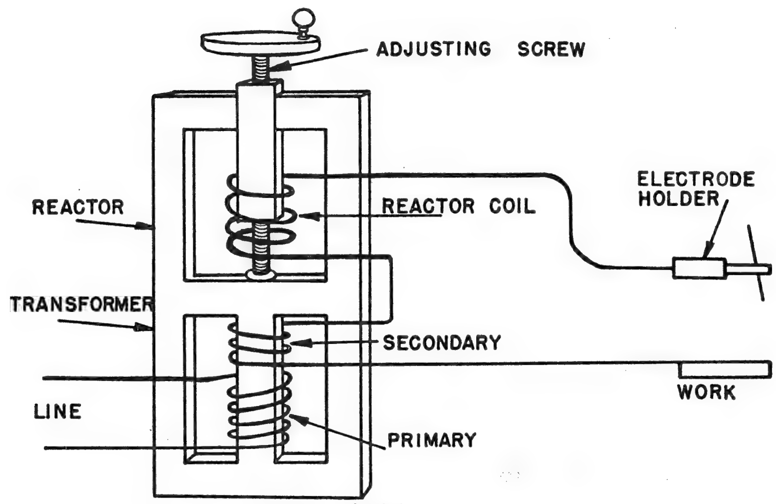


Fig. 4.18
Constant Voltage Transformer with Magnetically Adjusted Reactor Current Control.

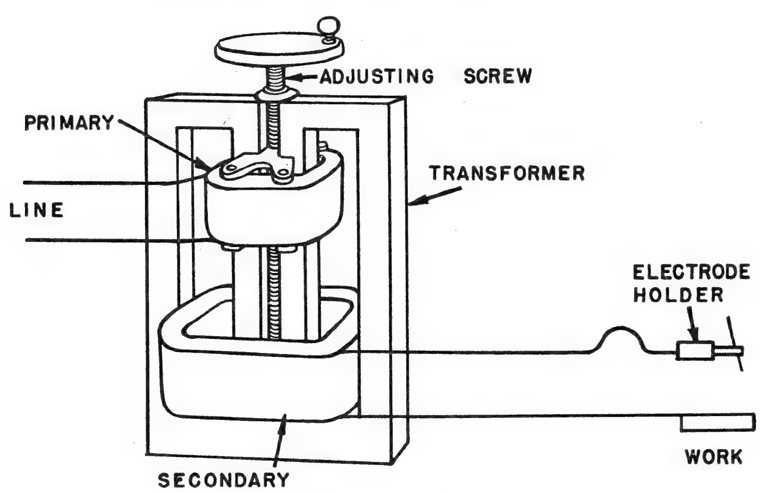


Fig. 4.19
Constant Current Transformer with Movable Coil Current Control.

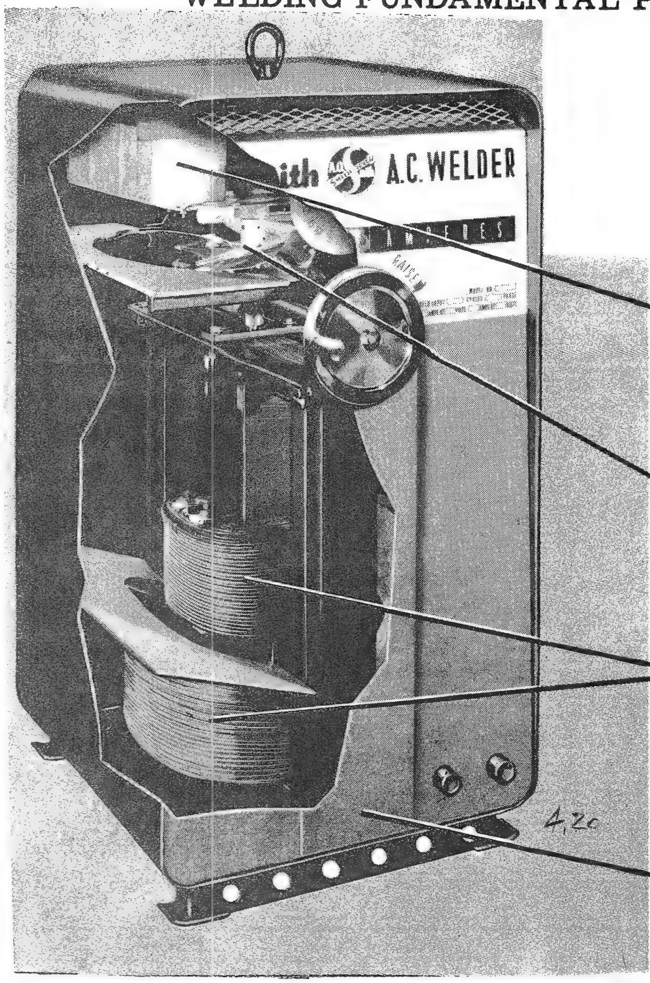


Fig. 4.20
Interior of an AC Transformer Welding Machine with Movable Coil
1. Power factor correction condenser - 2. Ventilation - 3. Primary and secondary transformer coils - 4. Case.

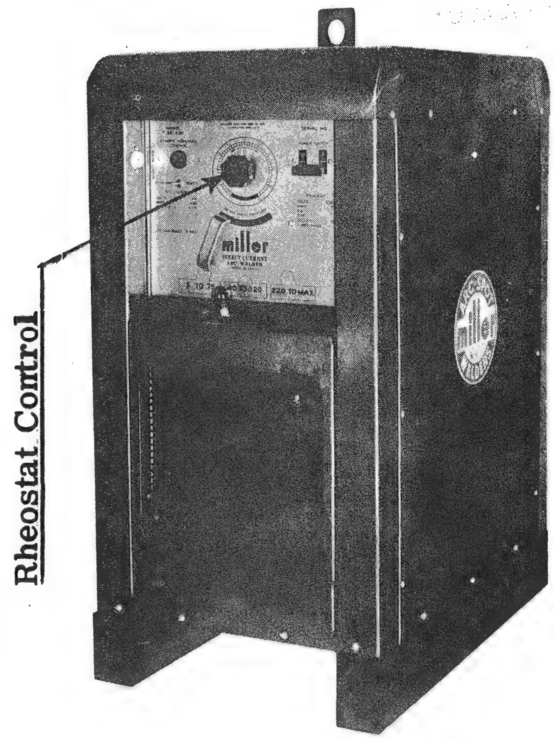


Fig. 4.21
Rectifier Welding Machine with Rheostat Control

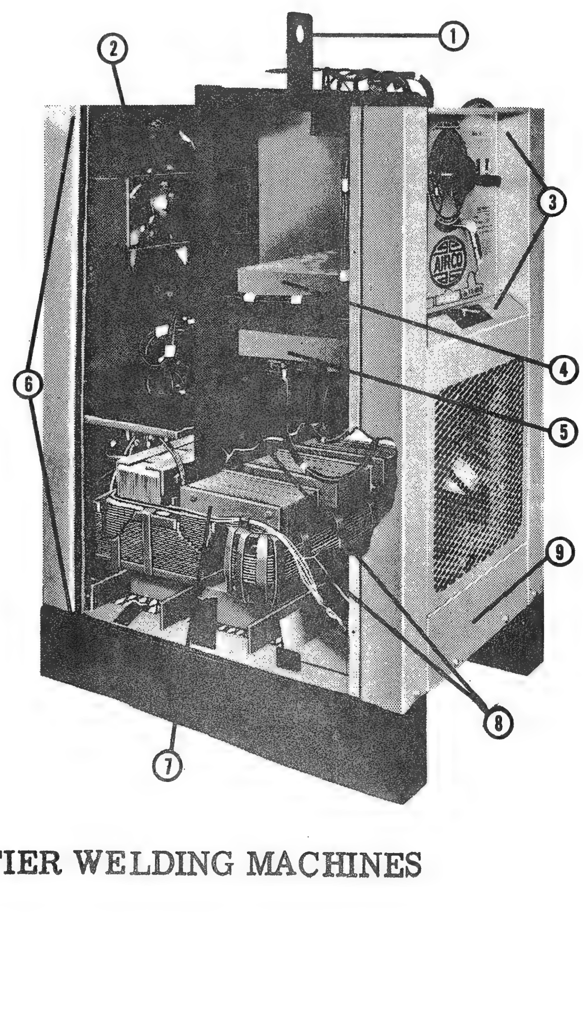


Fig. 4.22 ⟶
Interior of a DC Rectifier Type (Bumblebee AIRCO Series) Welding Machine
1. Lifting eye - 2. Cooling fan - 3. Recessed control panel containing: rheostat for fine current adjustments, selector switch, remote control outlet, reversing switch for change of polarity and primary switch - 4. Rectifier selenium stack - 5. Thermostat to reduce current output in the event of overheating - 6. Housing - 7. Transformer - 8. Baffle separating rectifier and transformer coils - 9. Concealed electrode and work terminals.

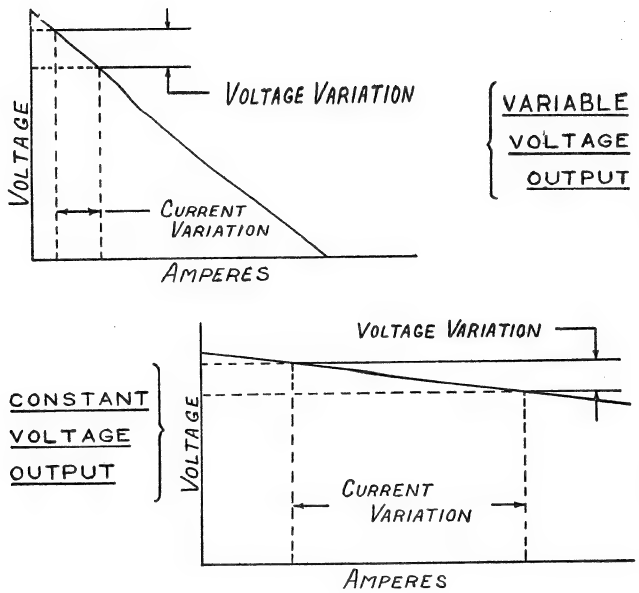


Fig. 4.23
Comparison of Characteristics of "Constant Current" and "Constant Voltage" Welding Machines
(For Variable Voltage - constant current output - see also Figures 4.10 to 4.13 inclusive.)

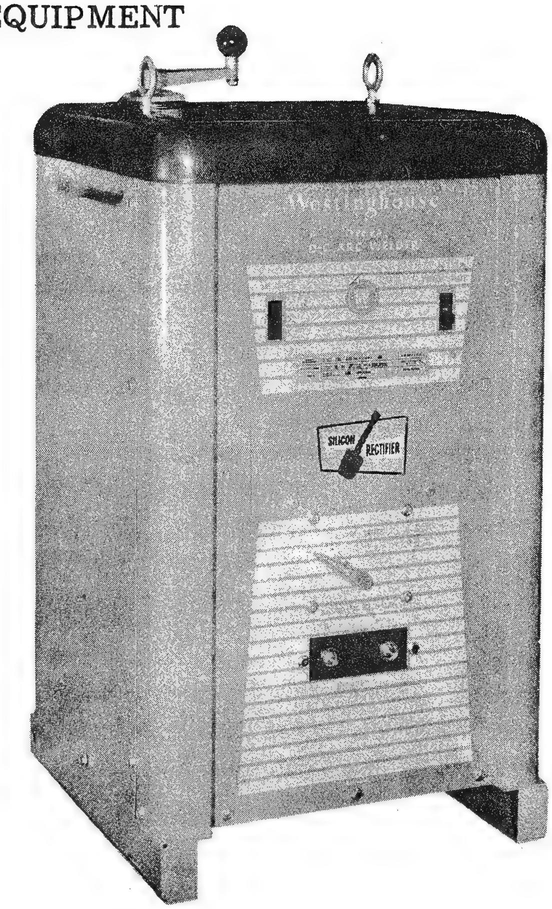


Fig. 4.24
Westinghouse Rectifier DC Welding Machine Type RA

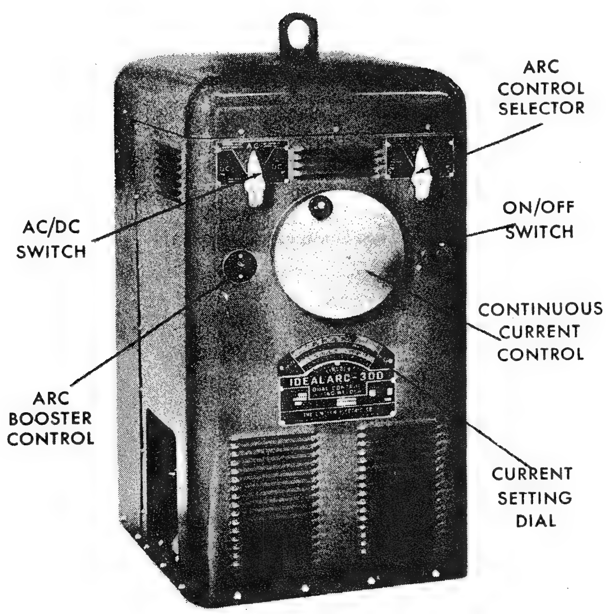


Fig. 4.25
Typical Combination AC-DC Welding Machine.

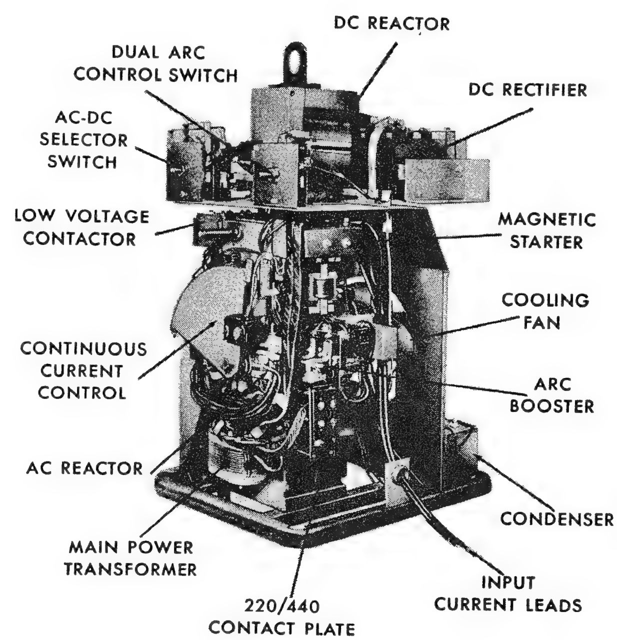


Fig. 4.26
Interior of the Machine Shown in Fig. 4.25

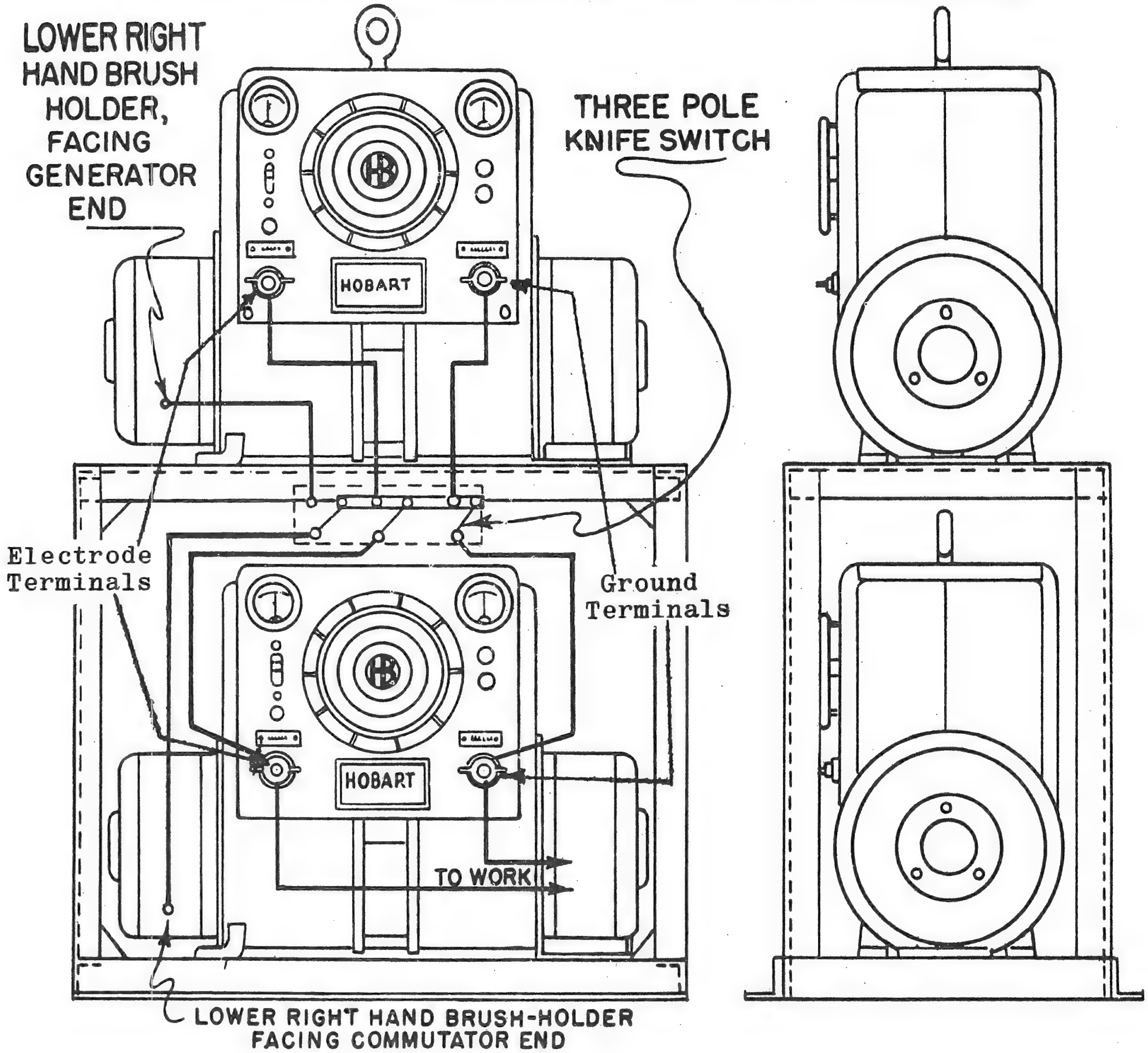


Fig. 4.27
Diagram Showing Parallel Operation of DC MG Sets.

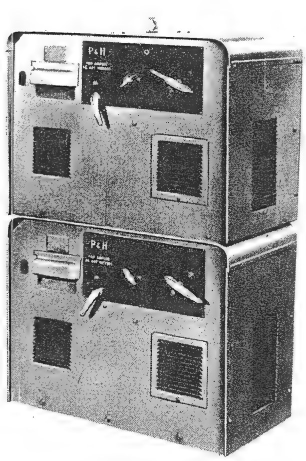


Fig. 4.28
The Stacking of Two Machines to Save Space.

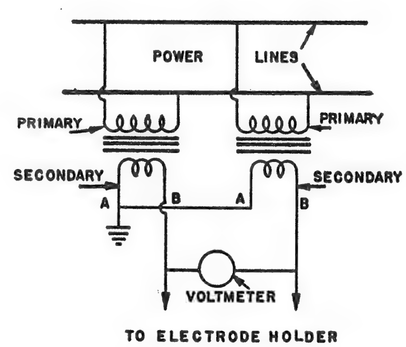


Fig. 4.29
Parallel Connection of Two Transformers (Method of Checking.)

PARALLEL OPERATION OF WELDING MACHINES

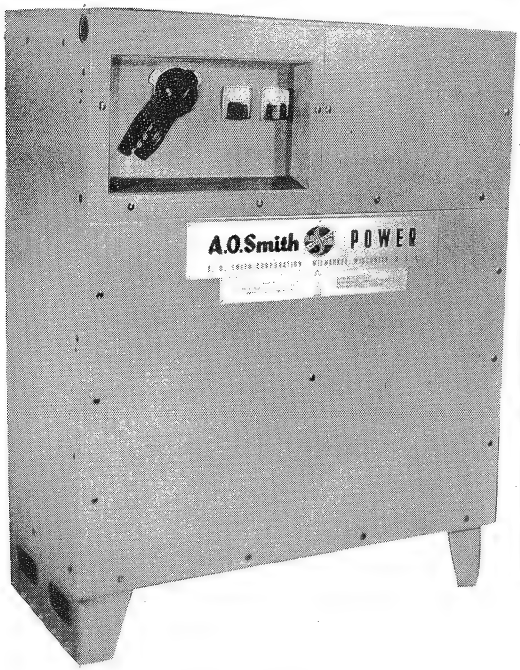


Fig. 4.30
Front View of 1500 Ampere Power Source for Multiple-Operator Welding.

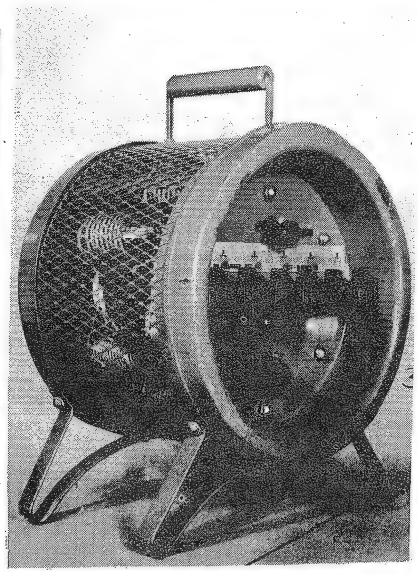


Fig. 4.31
One Man Portable Series Resistor Grid for a Constant Potential Power Supply.

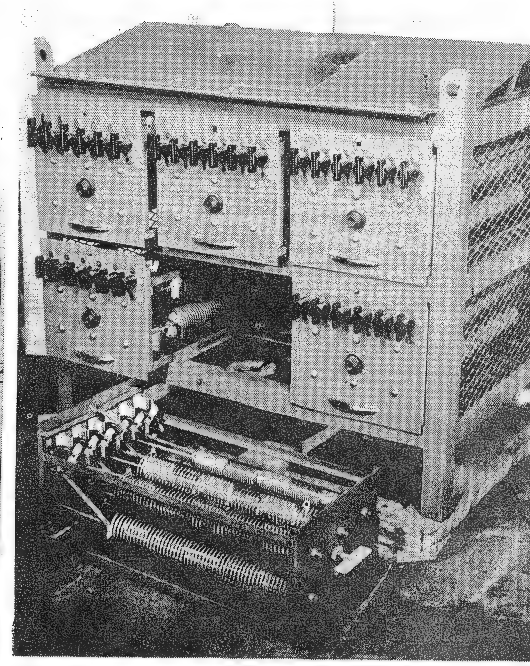


Fig. 4.32
Six Man Series Resistor Grid Bank for Multiple-Operator Welding.

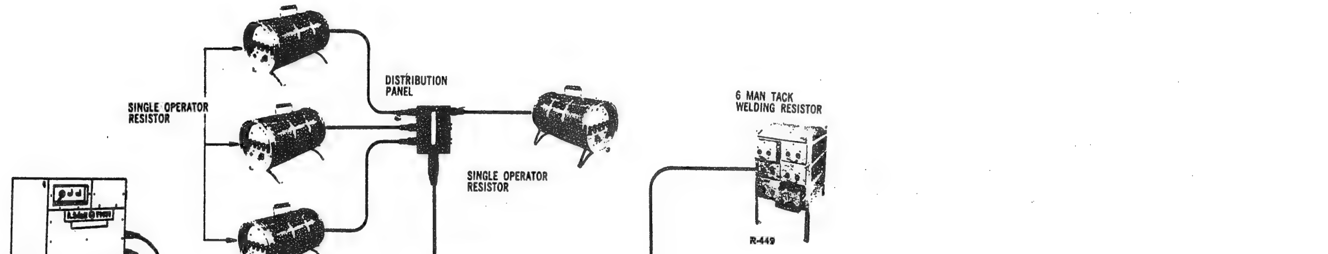


Fig. 4.33
Typical Multi-Operator Welding Installation Showing Power Sources and Resistance Boxes for Various Types of Loading.

Rating			Welding Current Range		
1	2	3	4	5	6
Amperes	Rated Load Voltage	Duty Cycle (%)	Minimum Amperes at Load of 20 Volts	Maximum Amperes at rated Load Voltage	Duty Cycle % at Maximum Amperes and Rated Load Voltage
150	30	50	20	185	30
200	30	50	30	250	30
200	40	60	40	250	35
300	40	60	60	375	35
400	40	60	80	500	35
600	40	60	120	750	35

Table 4.1
NEMA Standards for DC Variable-Voltage Arc Welding Generators.

Rating			Welding Current Range			
1	2	3	4	5	6	7
Amperes	Rated Load Voltage	Duty Cycle (%)	Minimum Amperes	at Load Voltage	Maximum Amperes at Rated Load Voltage	Duty Cycle % at Maximum Amperes and Rated Load Voltage
200	30	50	30	20	250	30
200	40	60	40	20	250	35
300	40	60	60	20	375	35
400	40	60	80	20	500	35
500	40	60	100	20	625	35
750	40	1-hr	187	30	935	—
1000	40	1-hr	250	30	1250	—
1500	40	1-hr	450	40	1875	—

Table 4.2
NEMA Standards for AC Transformer-Type Arc Welding Machines.

Rated Load, Amps. (Maximum Obtainable at Rated Load Volts)	Rated Load Volts	Duty Cycle, %	Minimum Welding Current, Amps.	Welding Machines with Power-Factor Correction, * Amps.	Welding Machines without Power-Factor Correction, * Amps.
(1)	(2)	(3)	(4)	(5)	(6)
130	25	20	20	27	33
180	25	20	20	37	46

* Current input at rated-load amperes (Column 1) and rated-load volts (Column 2) not to exceed these values.

Table 4.3
NEMA Rating for AC Transformer of Limited Input.

Rating			Welding Current Range			
1	2	3	4	5	6	7
Amperes	Rated Load Voltage	Duty Cycle (%)	Minimum Amperes	at Load Voltage	Maximum Amperes at Rated Load Voltage	Duty Cycle % at Maximum Amperes and Rated Load Voltage
200	40	60	40	20	250	35
300	40	60	60	20	375	35
400	40	60	80	20	500	35
500	40	60	100	20	625	35
600	40	60	120	30	750	35
1000	40	1-hr	250	30	1250	—
1500	40	1-hr	450	40	1875	—

Table 4.4
NEMA Standards for DC Rectifier-Type Welding Machines

NEMA STANDARDS FOR VARIOUS TYPES OF WELDING MACHINES

APPENDIX A

FUNDAMENTAL ELECTRICITY

This course has attempted to express the principles of arc welding processes and equipment without demanding of the student even an elementary knowledge of electricity. Such a knowledge is not deemed absolutely essential to the proper application and control of welding by operator, foreman or supervisor, but it will be a satisfaction to many to know the fundamental principles and electrical terms involved.

The electric current which is said to flow in a direct current welding circuit is produced in a specially designed generator driven by an electric motor or prime mover.

Also, as the student already knows, A.C. is frequently used for welding. A.C. is a current which is not flowing continuously in one direction, but as the name implies, alternates. This means that the current changes its direction of flow 120 times per second, or twice whatever frequency is available from the power company. However, for the present we will concentrate on D.C. to learn some of its characteristics.

The student must first of all understand the term "current". The flow of electricity in an electrical circuit is comparable to the flow of water in a pipeline. Fig. A.1 below shows the similarity between the hydraulic and electrical circuits.

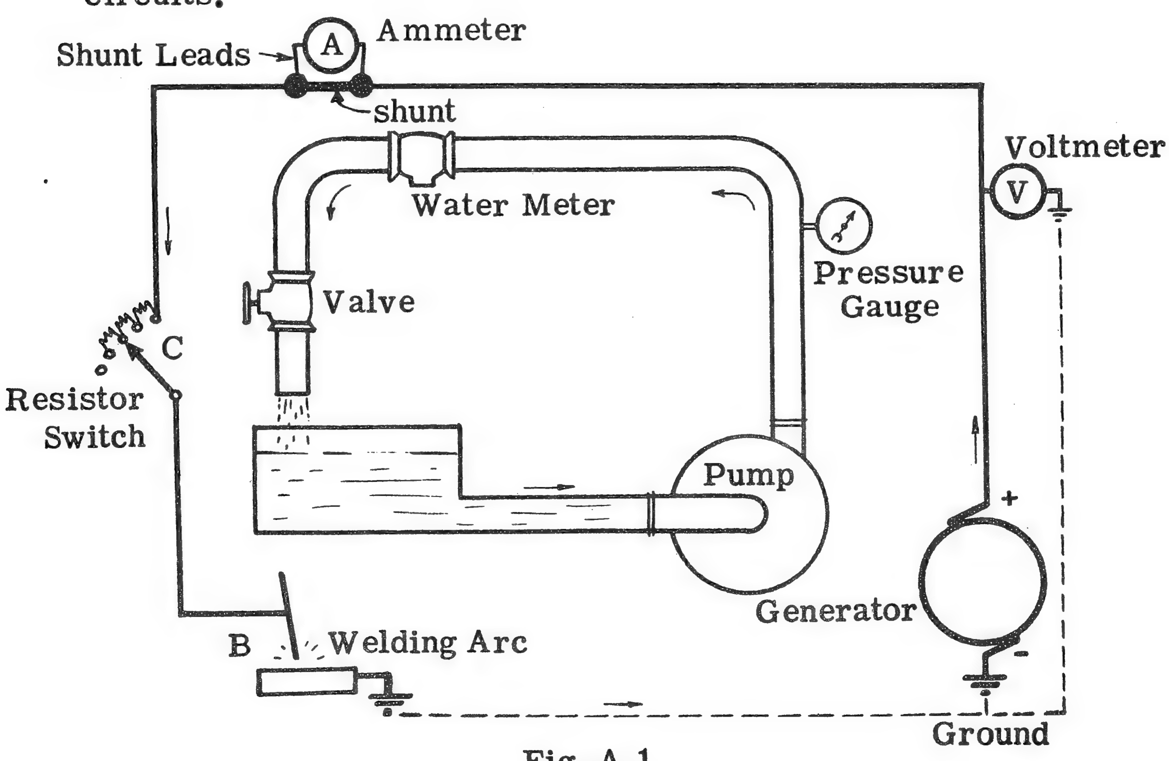


Fig. A.1.

The water flows through the pipes and out of the taps because of the pressure developed by the pumps at the water-works. The pressure of the water is measured in pounds per square inch; and the quantity of water flowing is measured in cubic feet per second and registered by a water meter. The same thing applies to the electric current. In order to have current flowing through a conductor (wire or cable) we must have a pressure originating at the electrical power plant generator. The pressure is the potential, or voltage, and is measured in volts, while the amount of current which flows through the conductor is measured in amperes.

Electrical Circuit

When a generator is running, electricity will flow from the positive terminal (+) through the electrical circuits (as indicated in Fig. A.1) back to the negative terminal (-). If the resistance at switch "C" is increased, the flow will diminish. If the circuit is broken at switch "C", the flow of electricity will cease. The electrical pressure (voltage), however, will continue to exist. As soon as the circuit is closed again, the current will be re-established.

Similarly, when resistance at the valve in the water pipe is increased by partially closing the opening, the flow diminishes; and when the valve is closed, flow ceases. The water pressure will exist as long as the pumps are operating, and when the circuit is completed again by opening the valve, the water will flow once more.

In Fig. A.1 the water flows back through the return circuit to the pump after performing the necessary work at the point of use; and the electricity flows back through the return circuit (ground) to the generator after performing the work at "B" which in this instance is the arc.

Magnetism and Induction

A magnetized object has what are called 'lines of magnetic force' flowing through it. These lines leave the object at one point called the North pole and return to it at another point called the South pole.

If an electric current is passed through a coiled wire, this coil will have lines of magnetic force through and around it and will have a North and South pole. If the coil is wound on a soft iron bar, the bar will be magnetized as long as the current is flowing through the coil. The number of lines of magnetic force will, within certain limits, depend on the strength of the current, and the position of the North and South poles will depend on the direction of the current. The strength of a magnet is indicated by the number of lines of force per square inch.

When a current in the coil around a soft iron bar is increased, the number of lines of force is also increased, rapidly at first and gradually slower. When the soft iron bar becomes "saturated", increasing the current will not produce more lines of force. Soft iron is employed for the core since this material loses its magnetism almost entirely when the current stops. The small proportion of remaining magnetism is called "residual magnetism". If a hard steel bar is used as core in the coil, the steel becomes a permanent magnet which may be used in the construction of magnetos, electrical instruments, etc.

Induction

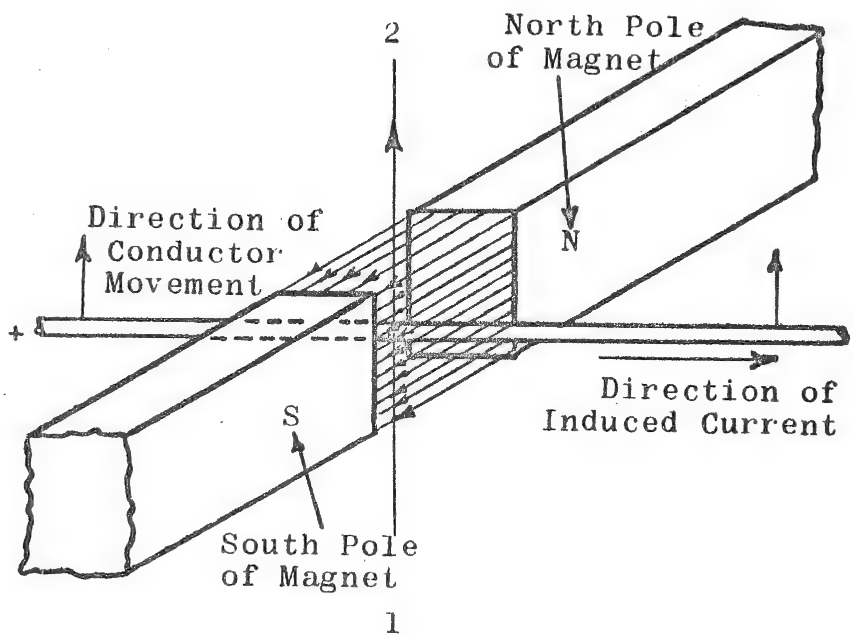
If a conductor is moved across a magnetic field in a direction perpendicular to the lines of force from 1 to 2 as indicated in Fig. A.2, page A.4, an electric current will be made to flow in the conductor. The direction of this induced current depends on the location of the poles of the magnet and the direction of motion of the conductor. The phenomenon is known as "INDUCTION".

Direct Current Generator

The direct current generator which transforms the mechanical energy of the prime mover into electrical energy is constructed on the principles dealt with in the preceding paragraphs. It consists essentially of two distinct elements, the "stator" (or magnet frame) and the "rotor" (Armature). The stator comprises the stationary magnetic poles which provide the magnetic field. The rotor is the rotating element or armature carrying the moving conductors. The stationary magnetic poles constitute the field and are made up of electromagnets of alternate polarity, usually two or more. The

armature has a system of copper conductors arranged on a soft iron core. The number of conductors required is determined by the output and speed of rotation of the armature.

The current to induce magnetism in the stationary magnetic poles may be supplied by an "exciter" which is a small additional "self-excited" generator as in the case of Hobart and Lincoln machines, or may be obtained from a rectifier which converts alternating current into direct . There are also "self-excited" welding generators on the market where the current for the stationary magnetic poles is produced within the circuit of the generator as in the case of the General Electric Welding Generator. The self-excited generator is very similar to the battery-charging generator in the average car and taps the exciting current from a "third" brush.



Principle of Current Induction

Fig. A.2.

Series and Parallel Circuits

There are commonly two fundamental circuits employed in an electrical system. The simplest type of circuit is the 'series circuit' in which each terminal of the electrical circuit is connected to the end of the preceding element in a chain-like fashion as shown in Fig. A.3, page A.6. The current which passes through all component parts is of equal magnitude.

Another common circuit is the parallel circuit as illustrated in Fig. A.4, page A.6. This circuit consists of more than one unit of electrical equipment arranged in such a manner that only a portion of the current flows through each component unit.

When two pieces of electrical apparatus are connected in parallel, one of these may be said to be 'shunted' across the other. An example is an amperemeter (ammeter) and its shunt. These will be described in more detail later.

Volts

In the hydraulic analogy it was explained that voltage is the electrical counterpart of hydraulic pressure. Electrical pressure is commonly referred to not only as voltage, but also as potential, or electromotive force. Voltage is measured with an instrument called a voltmeter which is connected to two points of an electrical circuit. The voltmeter always reads 'voltage difference' between two points. A voltmeter connected across the terminals of a welding machine is indicated in Fig. A.5, page A.6 at $^V1$ where it will give the voltage generated at the source when the circuit is open. If the machine is working, or welding is being done, the voltmeter ($^V1$) will measure the loaded voltage of the machine. This is equal to the arc voltage plus the voltage drop in the cables of the welding circuit due to their slight resistance to the current. If exact measurements of arc voltage are required, the voltmeter should be connected across the ground and the electrode holder at the point of welding ($^V2$). When the arc is broken, the instrument $^V2$ will measure the open circuit voltage. A voltmeter may also be employed to measure the voltage drop across a resistor which is indicated in Fig. A.5, page A.6 at $^V3$.

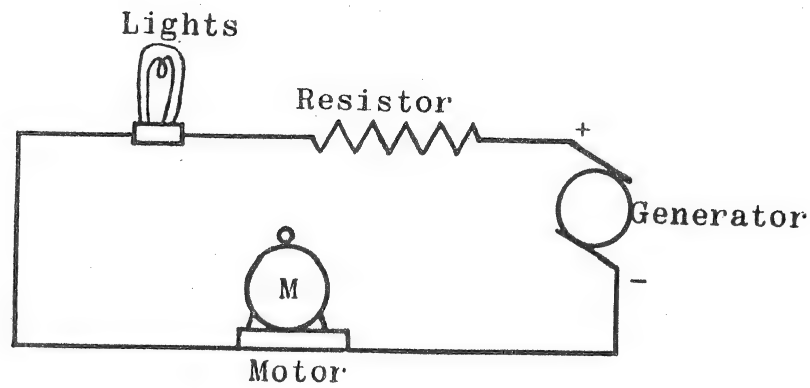


Fig. A.3
Series Circuit

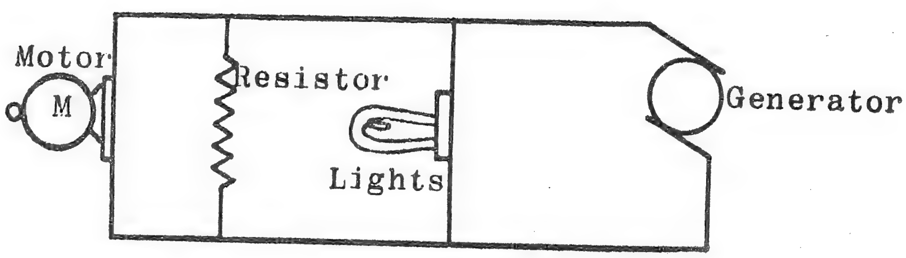


Fig. A.4
Parallel Circuit

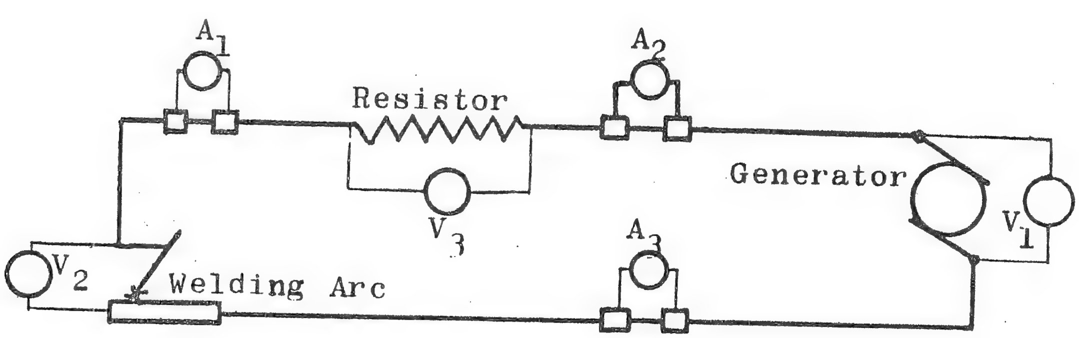


Fig. A.5
Possible Location of Instruments in a Welding Circuit
(See Page A.8)

In order to avoid damaging the instrument, it is important that the voltmeter be designed for the voltage range for which it is being used, and that its positive terminal be connected to the positive side of the circuit. It is particularly necessary to observe this precaution when the polarity of the machine is being reversed (by throwing the polarity switch). A conventional instrument as shown in Fig. A.6 below would also have to be reversed, and such precaution may easily be overlooked. Therefore it is preferable to install into the machine a so-called 'zero-centre' voltmeter as shown in Fig. A.7 below. No particular precautions are necessary when using this type of instrument because the pointer of this meter is free to move to left or right of the zero point.

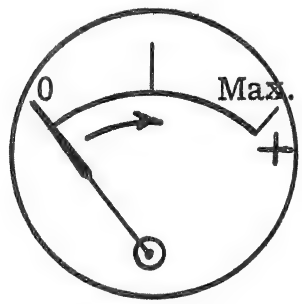


Fig. A.6
Conventional Type Dial

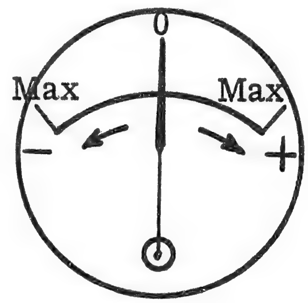


Fig. A.7
Zero-Centre Dial

Amperes

With reference again to the comparison with the hydraulic circuit, it may be recalled that the flow of water in a pipe in cubic feet per second is comparable to the current in amperes in an electrical circuit, which is measured with an ammeter. Since the ampere is a measurement of 'flow of electricity' it follows that the instrument should be installed in such a manner that the current has an opportunity to flow through the meter. In other words, the ammeter is always installed in series with the circuit.

The current employed for welding is of such magnitude that it requires cables and conductors of fairly large cross-section. To lead such large current through an ammeter would require a large unwieldy instrument; therefore a resistor, commonly referred to as a shunt, is placed in the circuit parallel to the ammeter so that the meter actually measures the

voltage drop across the shunt. This drop is usually in the order of millivolts (1 mV = $\frac{1}{1000}$ of one volt), and the dial of the ammeter is calibrated to indicate the amperes required to effect the voltage drop across the shunt. Actually, we have a voltmeter which is calibrated together with the resistance of the shunt to give accurate ampere readings. It is important that the shunt being used is rated to correspond with the range and rating of the meter. If the shunt resistance is too great, overloading and consequent injury to the meter will result. (See Fig. A. 1, page A. 1)

The mV rating and range of the meter are usually marked on the dial and these notations should not be overlooked. Likewise the shunt bears the ampere and mV ratings for which it is designed.

The ammeter may be placed at any point of the welding circuit and will always read the same current irrespective of its location. In Fig. A.5, page A.6 ammeters A_1, A_2 and A_3 will give the same current reading.

The precuations with reference to polarity of the meter are likewise to be observed with the ammeter if it is of the conventional type. The use of a zero-centre ammeter is as important as the zero-centre voltmeter.

Ohms

The consideration of the two electrical units, volts and amperes, leads logically to the third, the resistance.

It is known that water flowing through pipes or elbows is restricted in its free movement. There is no unit to express this resistance to flow in an hydraulic circuit. It is usually referred to as a pressure drop. Similarly, the electrical current encounters resistance at all points along the circuit, in the wire, cables, shunts and contacts. The unit used in measuring this resistance in an electrical circuit is the ohm. The ohm may be defined as the resistance required to produce a voltage drop of <u>one</u> volt with a current of <u>one</u> ampere. It is obvious that the resistance to water flow and to electric current produces a similar effect, namely, a pressure drop or in electrical terms, a voltage drop.

There are electrical instruments available to measure the resistance in ohms; however, they are not commonly used for welding circuits.

Ohm's Law

In the previous paragraph we referred to the relationship which exists between voltage, current and resistance. This relationship is known as Ohm's Law. This law may be stated simply:- In a D.C. electrical circuit the voltage drop is equal to the resistance multiplied by the current.

This may be expressed by means of the formula $E = I \times R$, where

E = voltage drop

I = current in amperes

R = resistance in ohms

This is an equation which can be rewritten to permit the solution for any one factor in terms of the other two which are known, i.e. the current can be calculated if voltage and resistance are known, as follows:-

$$I = \frac{E}{R}$$

and the resistance can be calculated if current and voltage drop are known:-

$$R = \frac{E}{I}$$

Example

What is the voltage drop in a D.C. welding circuit employing a No. 2 cable, the welding lead being 75' long, the ground lead being 100' long and employing a 3/16" electrode using 200 amperes?

The specific resistance of the cable can be found in any electrical handbook as 0.0156 ohms per 100 ft.

Therefore the resistance of the cable will be:-

$$\left(\frac{75 + 100}{100} \times 0.0156\right) \text{ i.e. } 1.75 \times 0.0156$$

The voltage drop in this case is:-

$$E = I \times R = 200\ (1.75 \times 0.0156) = 5.5 \text{ volts}$$

In this calculation we have neglected to include the resistance of cable joints and connections which add to the voltage drop by approximately one additional volt per joint and more if they are not tight.

For a transformer welding circuit, which is always A.C., there are inductive reactance effects which have already been referred to on page 4.16. This formula would thus not apply to A.C.

Power

The next subject of our study is the electric power required to operate various welding sets. The preceding paragraphs discussed and referred to direct current. Alternating current is generally used to drive the electric motor or it may be used as a source of welding current. This type of current involves different theories and methods of calculation too involved to be included in this elementary study.

The term "power" is new in this discussion, hence it is deemed advisable to develop its significance from fundamental concepts.

To create power, it is necessary that work be done and the unit for measuring such work is the foot-pound. One foot-pound is defined as the work required to life a weight of one pound to the height of one foot. The performance of 33,000 foot-pounds per minute (550 foot-pounds per second) is established as one horsepower.

It might be important to point out that the unit of power contains the element of time.

Watts and Kilowatts

In the hydraulic analogy of our earlier explanation, it has been shown that voltage corresponds with pressure while current corresponds with flow. Therefore, the same fundamental consideration for the generation of power exists in both cases.

In a water turbine, the head of water, or pressure, and the volume of water measured in Cu. Ft./Sec. create the horsepower of this prime-mover.

Electrical power is measured in terms of the standard units of volts and amperes and the unit of electrical power is known as the Watt.

Mathematically, the power may be expressed in watts (W) as:-

$$W = E \times I$$

Since the watt is a rather small unit, electric power is usually defined in 1,000 watts or one kilowatt (KW).

By experiment it has been established that the relation between mechanical power (horsepower = HP) and the electrical power (Watt = W) can be expressed as follows:-

$$1 \text{ HP} = 746 \text{ W} = \frac{746}{1000} \text{ KW or } 0.746 \text{ KW}$$

If we consider a 200 ampere standard electric welding machine operating at 200 ampere capacity and 40 volts arc voltage, we can now calculate the horsepower of this unit as:

200 amps x 40 volts = 8000 watts

and as 1 HP equals 746 watts we

have 8000 ÷ 746 = 10.7 horsepower

We know, however, that the standard 200 ampere welding machine is powered with a much larger motor. The reason for this is the fact that in driving a generator, there are certain losses such as air resistance in armature and fan; friction in bearings and electrical losses in the form of resistance in the electrical circuit of the generator. To overcome all these losses, additional power is required and the ratio between the power delivered by the welding machine and the actual power required to drive the generator is referred to as the generator efficiency which is usually expressed as a percentage. Thus efficiency is defined as:

$\frac{\text{Output}}{\text{Input}} \times 100$. A typical overall efficiency of a standard make motor-driven electric welding machine is approximately 60%. This includes the losses in both motor and generator. The efficiency varies with the load and the efficiency is lower with smaller loads. Therefore it is uneconomical to use a large machine for small electrodes.

The motor sizes for standard 40 volt electric motor-driven welding machines are:-

200 ampere - 12 HP
300 ampere - 20 HP
400 ampere - 30 HP

Another consideration in dimensioning the motor for a given welding machine is the load or operating factor.

It has previously been noted that an operator does not weld continuously for sixty minutes in every hour. There are delays such as changing electrodes, setting up the work, rest periods, etc., so that the actual welding time will be less than one hour. The ratio of the period in which welding is performed to the total period is called the duty, operating or load factor and is expressed as a percentage. The variation of the duty factor may be from 20 to 80% dependent upon the nature of the work. This would correspond to a welding period of from 12 to 48 minutes per hour.

In calculating the HP required to satisfactorily operate a welding machine, usually 60% is assumed as a duty factor, which is to say that the motor which drives the unit is under load only 60% of the time and is therefore designed correspondingly smaller than if it were to be in continuous use. This must be considered when using a welding generator at a 100% duty factor as for thawing out frozen pipelines. In such cases, the maximum permissible load on the machine should not exceed 60% of its welding rating. In addition, for pipe thawing, which is a low resistance operation, the current will be that much higher than indicated on welding dials. To be safe, such machines when used on pipe thawing should be set by an ammeter to prevent overloading.

LESSON 5

ARC WELDING ELECTRODES

The primary purpose of studying electrodes in this course is to ensure that the student is aware of the principal types of electrodes available for a wide variety of applications, and more particularly that he may be able to make an intelligent and suitable choice both with respect to quality, ease of operation, initial costs and operating costs. As a matter of interest, certain information as to coating constituents and manufacture is included to round out the student's knowledge, although this has little bearing on his proper choice and application.

AVAILABLE ELECTRODES

The student has already learned that by the proper choice of electrode material, including both core wire and coating, almost any metal may be deposited. A great variety of electrodes are made, including those for surfacing as well as for the more usual purpose of fabrication.

All these many electrodes fall into seven categories, which may be designated as follows:

1. Mild Steel Arc Welding Electrodes;
2. Low Alloy Steel Arc Welding Electrodes;
3. Stainless Steel Arc Welding Electrodes;
4. Surfacing Metal Arc Electrodes, both ferrous and non-ferrous;
5. Nickel and Nickel Alloy Electrodes;
6. Aluminum and Aluminum Alloy Metal Arc Welding Electrodes;
7. Copper and Copper Alloy Metal Arc Welding Electrodes.

Of these, the first three will be dealt with in this lesson. Codes pertaining to these and the remainder will be noted in the bibliography at the end of this lesson.

Within the above categories the electrodes may be classified on the basis of the physical and/or chemical characteristics of the deposited weld metal. In addition electrodes are descriptively characterized in accordance with their type of coating, of which there are two main groupings - lightly coated electrodes and heavily coated electrodes.

Lightly Coated Electrodes

The consumption of electrodes of the above group is now small

compared to that of the heavy coated groups, but there is no doubt that many students will recall the time when only this type of electrode existed. Three types will be discussed under this heading:-

1. Sulcoated Rods (Coating applied before drawing)

The electrodes of this group are commonly known as "bare" or "sulcoated" rods. The coating is simply a mixture of rust and lime. Pickled rods are subjected to successive water spraying and drying periods, the red oxide of iron (rust) being formed on the surface. The coiled rods are then dipped in a lime solution, baked and drawn to the desired diameter. A good sulcoat is chocolate brown in color and the wire has a shiny finish. The wire is usually supplied in 14 inch lengths and for most work the electrode is gripped near the centre.

Improved arc stability is the most noticeable effect of this coating. The penetration is low, arc hesitant and freezing of the electrode to the work is common. Operation on D. C. using straight polarity (electrode negative) is recommended. A satisfactory arc cannot be maintained with alternating current. No slag is formed, only a light grey scale being present, which can be removed by brushing.

Because the molten globules pass across the arc gap unprotected, considerable oxidation takes place, and only 20% of the carbon and manganese present in the core wire finds its way into the deposit. The oxygen and nitrogen content of the weld metal is high, and these factors combine to produce a deposit which has little ductility and resistance to impact.

Typical physical and chemical properties are shown below:

CHEMICAL		PHYSICAL	
Carbon	0.05%	Ult. Tensile Stress	52,000 p.s.i.
Manganese	0.15%	Yield Point	41,000 p.s.i.
Oxygen	0.25%	Elongation in 2"	6%
Nitrogen	0.15%	Izod Impact	9 ft. lbs.

The foregoing physical properties indicate that this electrode should not be used on work subjected to severe stresses nor will it stand much impact or elongation. Its fatigue resistance is also low and it should not be used where alternating stresses are encountered.

2. Rolled Electrodes (Coating applied after drawing)

The coating is usually a mixture of such arc stabilizers as calcium carbonate, fluorspar and titanium dioxide, suspended in a dilute solution of sodium silicate. A very light coating is applied to the bright core wire by tumbling the cut wire in a cylinder lined with canvas on which a thin layer of coating is spread. A brief drying period follows and the finished rod usually has a greyish white appearance. The coating is approximately 0.0005"thick and no brushed section is necessary to make contact in the holder.

3. Dipped Mild Steel Electrodes (Coating applied after drawing)

The constituents of the coating on dipped electrodes are very similar to those for rolled electrodes. The solution is made more viscous by a higher concentration of sodium silicate and this permits a thicker coating to be applied to the bare wire. Drying takes slightly longer, and one inch of wire at the end is left uncoated for contact in the holder. The opposite end is ground free of flux to permit easy striking.

In the latter two types the arc stability is slightly better than that of the sulcoated rod but the metal deposited has the same physical properties and is used in similar circumstances.

Heavily Coated Electrodes

It soon became apparent that if welding was to become an accepted method of fabrication in all industires, electrodes which would easily and cheaply deposit sound ductile metals would have to be developed. This was accomplished through the formulation of chemically balanced coatings which are relatively heavy and thick.

By such a coating the physical characteristics are much improved and deposited metal of the following physical and chemical properties may be obtained:

CHEMICAL		PHYSICAL	
Carbon	0.10%	Ult. Tensile Stress	68,000 p.s.i.
Manganese	0.47%	Yield Point	53,000 p.s.i.
Oxygen	0.06%	Elongation in 2"	17-30%
Nitrogen	0.01%	Izod Impact	25-75 ft. lbs.

A heavy coating may be applied by successive dipping or more commonly nowadays by a process of extrusion.

The reader will already have noted from Fig. 3.3(b), page 3.2 that a heavy coating provides:

1. A gaseous protective shield;
2. Slag to protect the deposited metal;
3. A cup or inverted crucible which projects beyond the core wire and provides mechanical protection to the depositing metal.

The slag which is a fused compound of the flux ingredients, performs several important functions, including the following:

(a) The molten slag passing across the arc forms a mechanical shield, protecting the metal from oxidation.

(b) It is capable of dissolving and holding in solid solution, oxides of iron and manganese which are formed by oxidation and which would be harmful to the physical properties if present in the weld metal.

(c) The shape and smoothness of the bead is controlled by its nature, volume and surface tension.

(d) The rate of cooling of the deposited metal is decreased, thus reducing the tendency to cracking.

(e) Air is excluded from the surface of the deposited metal preventing the formation of scale and leaving the bead bright and shiny after the slag is removed.

The coating, besides producing both the slag and gas protection, serves a number of other purposes such as:

1. Provides alloying elements to the weld metal such as manganese, chromium, vanadium by which the physical properties may be altered. For example, electrodes giving 60,000 and 70,000 p.s.i. tensile may, and usually do, have the same core wire, but the higher tensile strength of the latter may be obtained by adding the proper amount of ferromolybdenum to the coating.

2. The arc is more readily established and maintained.

3. There is less tendency for the electrode to freeze or stick to the work.

4. Alternating current may be readily used if the coating is designed accordingly.

5. Prevents the sides of the electrode accidentally arcing to the work since most coatings are non-conductors.

The only disadvantage of a heavily coated electrode is the attention required to control the molten slag. This is particularly so in vertical welding and to some extent for overhead. On the whole, however, operators find the heavily coated electrode preferable and easier to use. Less skill and less training is required than for "bare" or lightly coated electrodes.

MATERIAL FOR ELECTRODE COATINGS

Having seen the advantages which are derived from coating electrodes, it is of interest to learn of the various ingredients which comprise these coatings and the functions of each.

Rutile

This mineral is found in several places in North America and usually contains around 90% titanium dioxide. It varies in color from tan to black. This compound is excellent for making the arc smooth and stable. When present in fairly large quantities it forms a hard black slag which gives a fine smooth finish to the deposit.

China Clay, Silica, Mica, Etc.

These minerals are quite common in many places throughout

the world. Their main function in the coating is to provide slag volume. Also by varying the additions, the friability (crumbliness), rate of freezing, viscosity and surface tension of the slag can be adjusted.

Potassium Feldspar, Potassium Titanate, Etc.

Compounds or minerals containing potassium are very good as arc stabilizers and ionizers. Arc ionization simply means putting oxides, or the like, into the arc atmosphere, to facilitate and stabilize the passage of electric current. Where possible, minerals are used in preference to manufactured chemicals because of their lower cost.

Cellulose

This is a product of wood pulp, pure white in color, which burns in the arc and produces gases which protect the molten metal from oxidation. Where present to any extent it retards the fusing of the coating, and forms an inverted cup type shield of the coating itself. It gives direction to the gases and forms an actual mechanical shield about the transferring globules.

Ferro Manganese

This is a product made in a special furnace by melting manganese bearing ores with a flux, usually limestone. The alloy contains approximately 80% manganese. It removes oxygen from the arc by combining with it and forming an oxide which passes into the slag. The percentage present in the coating is also governed by the amount of manganese that is required in the weld metal.

Iron Oxides (Magnetites, Hematite, Etc.)

These ores are found in many countries and are used widely in the manufacture of iron and steel. In electrode coatings they are used to form heavy slags which are capable of holding in solid solution large quantities of oxides which may be formed in the welding operation. They may be red or black according to type and where they are mined.

Water Glass (Sodium Silicate)

This compound is manufactured by dissolving a fused compound of soda and silica in water. It is a heavy liquid, quite viscous and sticky and is used for binding the various ingredients together in a form suitable for extruding them on to the core wire.

Iron Powder

NOTE: IMPORTANT

Iron powder is added to the coatings of some electrodes in amounts varying from 10 to 50% or more. Its purpose is to add additional filler material to that produced by the electrode core wire and thus increase the rate of welding. It also has a tendency to improve appearance.

Dozens of different chemicals, minerals and ores are used in the production of electrode coatings, but the combinations developed all achieve a few definite purposes. Most coatings contain from six to ten ingredients and the proportions used are determined by the special type of work for which the electrode is to be used. Those quoted above are typical

examples of coating constituents which fall into the following main groups:

(a) Arc Stabilizers

(b) Deoxidizers

(c) Slag formers

(d) Protective gas producers

(e) Alloy additions

(f) Metal additions

(g) Liquid binders

Although the majority of mild steel and low alloy electrodes are today extruded, some of the stainless steel electrodes and especially those of special analysis produced in relatively small quantities are dipped. Modern dipping equipment and methods result in both consistency and quality.

Core Wire for Mild Steel Electrodes

Contrary to what might be expected, the core wire for a wide range of steel electrodes is the same. As has been already noted, a variety of properties may be obtained through alloying elements obtained from the coating.

Core wire is usually a low carbon rimmed steel. Quality is high and must be uniformly maintained. A typical analysis is as follows:

Carbon	0.10%)	
Manganese	0.50%)	
Sulphur	0.03%)	Total Metalloid Content 0.67%
Phosphorus	0.04%)	
Silicon	NIL)	
Iron	99.33% (100-0.67)	

It can be seen that carbon and the other elements exist in very small quantities in this mild steel, but an increase in any one, and particularly carbon, can have a very marked effect on the properties of the steel. In steels of this type, carbon and manganese are actually regarded as being alloying elements, while the others are looked upon as impurities.

CLASSIFICATION OF MILD AND LOW ALLOY STEEL ELECTRODES

The economy, ease of operation, quality of welds, etc. which the heavy coated electrode introduced, increased electrode consumption tremendously, and in a short period the welding industry had innumerable electrodes all carrying their own particular trade name. After some time the American Welding Society decided that to simplify the situation, electrodes would be split into groups according to their operating characteristics and the physical and chemical properties of the metal deposited.

The electrode classification numbers originally set up by the AWS have been generally accepted and are used by the Canadian Standards Association and others. It is important that this system be understood.

Under the AWS and CSA system for example, one commonly used mild steel electrode is designated as E6010, which is one of a series known as the E60 group, and may be interpreted as follows:

1. The letter E preceding the electrode number denotes the electrode is intended for electric arc welding.

2. The first two figures indicate in thousands of pounds the approximate tensile strength of the deposited metal; in this case 60,000 pounds per square inch (p.s.i.).

3. The third figure of the group gives us information as to the welding positions in which the electrode may be satisfactorily operated -

   1. - All positions.
   2. - Horizontal fillet and flat position only.
   3. - Flat position only.

   With E6010, since the third figure is 1 it is an all positional rod, being readily used for welding in the flat, vertical, overhead and intermediate positions.

4. The last two figures combined have no logical relationship or significance in themselves but users learn to associate with them certain characteristics of coating, slag, penetration and appearance and so they take on a meaning.

In addition to the E60 series, there is also an E70, E80, E90, E100, E110, and E120 depending on the weld metal strength. This strength is usually attained by adding small quantities of alloying elements to the coating and these series fall under the category of Low Alloy Steel Arc Welding Electrodes. High alloy electrodes are of course the stainless and corrosion resistant types and are differently designated as will be explained later.

Also it should be noted that some electrodes attain 70,000 p.s.i. without the addition of alloys and are therefore usually considered as mild steel electrodes. For the student's information, these include E7014, E7015, E7016, E7018, E7024 and E7028. They will be later fully described as E6014 and E7014; E6015 and E7015 etc. Since these electrodes meet also the tensile requirements of the E60 series, they may be classified in this grouping. They are however the only exceptions. Otherwise an electrode classified under one classification shall not be classified under another according to American Welding Society and Canadian Standards Association requirements.

Another point the student should note is that all equivalent electrodes of each series have the same operating characteristics. Their only difference would be in physical or chemical properties. For example, an E6010 would have the same type of coating and operate in the same way as an E8010.

Generally speaking the electrodes in the E80, E90 and E100 series are restricted to either a cellulose or low hydrogen coating and the higher tensile rods in the E110 and E120 classes are virtually all low hydrogen types. This is mainly because low hydrogen coatings by nature lend themselves far better than any other type to the transfer of alloys in the deposited metal.

Table 5.1 shows the operating characteristics of both mild and low alloy steel electrodes. Where **XX** is used the student should understand that the number designating any series may be substituted. Thus **EXX10** could be E6010, E7010, E8010, etc. It should be noted that E6012 has no counterpart in any of the higher series since its quality does not warrant its use. It is therefore found only in the E60 group.

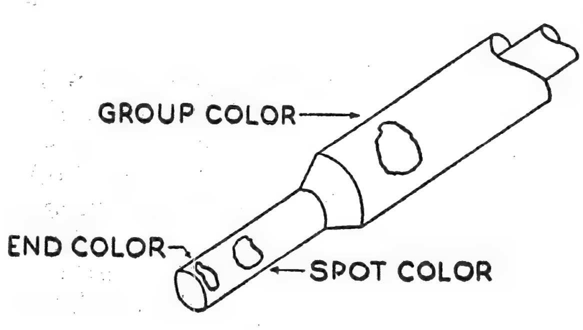
STANDARD MARKING FOR ARC WELDING ELECTRODES

Students will recognize that in view of the difference in the properties of electrodes, it is important that the right electrode always be used. It might be highly dangerous to use an electrode of low tensile strength where one of high strength was required or if stainless properties were called for. Therefore all electrodes should be properly marked and all users should know what the markings signify.

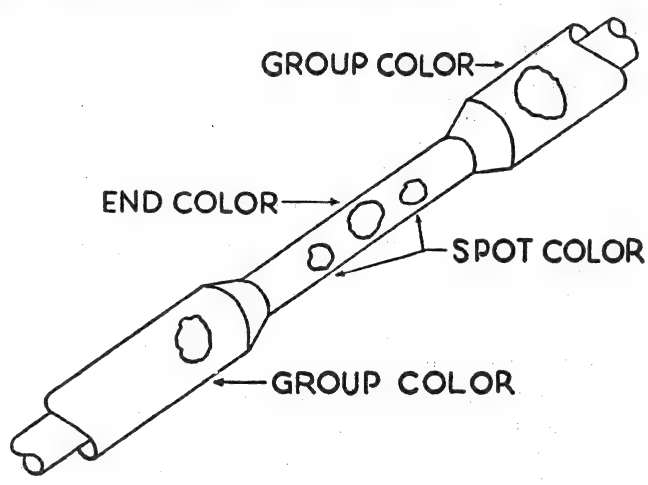
The National Electrical Manufacturers Association (NEMA) has developed and agreed on Standard Color Markings which are listed herewith in tables 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8 and 5.9. As an alternative American Welding Society and Canadian Standards Association classification marks may be imprinted on the coating.

Electrodes may have no marking (E6010 only) or one, two or three colors, known as group, end and spot color.

The position of these color markings is shown below.



Location of Color Markings for End-grip Electrodes



Location of Color Markings for Center-grip Electrodes

Note 1 - In the case of center-grip electrodes, the end color will be centrally located, and the spot color will be located on each side of the end color.

Note 2 - Color references in the above drawings are used only to denote sequence of colors; they are not intended to show the configuration of the colors to be applied.

THE E60 ~~SERIES~~

The following description of the various electrodes of the E60 series may be taken as applying also to each of the higher series, i.e. E70, E80, etc. For a summary of these various features see Table 5.1. Mechanical properties are given in Table 5.10 and typical current ranges in amperes in Table 5.11.

E6010 Type (no color)

Electrodes of this type are used on D.C. current, reverse polarity only.

The flux coating is high in cellulose and is usually white or grey in appearance. High cellulosic content is designed to produce large volumes of carbon dioxide, carbon monoxide and water vapor which effectively protect the molten metal passing across the arc.

The combination of coating constituents causes considerable liberation of heat in the base metal (negative pole) with resultant deep penetration. Care must be taken to ensure that the operational procedure is correct. The deeply penetrating arc can give rise to undercutting with careless handling of the rod.

Because of its high organic content (usually cellulose which burns and goes off as a gas) the slag volume is low, and in many cases it does not cover the weld deposit completely. The slag is fast freezing and for this reason it is ideal for welding in the vertical and overhead positions. Being porous, light and friable, it is easily removed, but its effect on bead formation is only slight and the bead is comparatively rough.

With the core wire melting faster than the coating, a cup frequently 0 to 1/16 in. deep is formed at the end of the rod, and this enables the operator to hold the rod very close to the work without it sticking. Holding the electrode close gives added protection against oxidation and decreases the spatter loss. Any increase in arc length or excessive current causes high spatter loss in this type.

The metal deposited is of very high order. Porosity is usually negligible and the ductility is high, usually ranging from 22 to 30%. Until the development of the low hydrogen type electrode, the E6010 produced the most sound and ductile deposit in the vertical and overhead positions.

Because of its good quality metal and deep penetration, this type is favoured in all classes of work where the structure or weldment is subject to stress reversals, triaxial stresses, etc. Shipbuilding is a

typical example of an industry that uses tremendous tonnages. Welding of fuel tanks and pipelines is usually carried out with this rod. It is particularly good for the joining of square groove butt joints where 100% penetration is required. Also it is employed for welding galvanized material. Although of high penetrating characteristics, it may be useful employed where fit-up varies. Also, because of its penetrating properties, it is often used to ensure deep fusion and high quality in the first and most critical run while other electrodes are employed for subsequent runs.

The electrodes are made in all the standard diameters, 1/16" to 5/16", and generally in 14" lengths only, although some larger sizes are made in 18" lengths. Deterioration of the coating due to heating of the core wire may occur during welding. Cellulose decomposes at temperatures as low as 180° F., and it is unwise to use high current densities with this type. Moisture also plays an important part in the coating, and care should be taken to prevent absorption or loss of moisture* through unfavourable storage conditions. Excess moisture results in arc instability and increases spatter loss while excessively low moisture reduces penetration and causes pinholes and blistered craters.

E6011 (Spot color - blue)

With the advent of alternating current welding came the demand for an electrode having all the good qualities of the E6010 electrode and yet capable of being used on an A. C. transformer.

Combining these requirements is almost an impossibility because ingredients which aid one characteristic oppose another. However, electrodes which meet code requirements have been developed by compromising slightly, mainly on the question of depth of penetration.

The cellulosic content is usually lower and easily ionized materials, such as potassium feldspar, are added to increase arc stability at low open circuit voltage and low welding currents. Spatter with the E6011 electrode is generally finer and readily removed. When used on A. C., the arc can be recognized as being somewhat more noisy than an E6010 on D. C.

The electrodes are used on work similar to that indicated for E6010 and, as stated above, the characteristics are very close to this type.

E6012 (Spot color - white)

Commonly known as the general purpose rod, almost every welder will have used this type. Usually tan or light brown in color, it is made in all diameters up to 5/16" and in lengths varying from 9" to 18", depending on the diameter. Originally developed for use on direct current straight polarity, most rods can be satisfactorily operated on A. C. and D. C. reverse polarity.

Rutile is the basic coating constituent, clays, silica, feldspar, etc. being added to aid extrusion, arc stability and slag characteristics. The cellulose content is quite low, protection for the molten metal being

* See also Detrimental Action of Moisture and Hydrogen.

afforded by the shield of molten slag.

The slag is usually quite heavy bluish black in color and very fast freezing, making it easy to use in all positions. It is fairly easy to remove although it tends to cling to the upper edge of horizontal fillet welds, and is a little harder to remove when deposited in a downhand fillet. These slag characteristics produce single pass fillets which are slightly convex, the edges of the bead being sharply defined. The bead is smooth and bright with fine ripples and ends in a shallow dense crater.

Penetration is decidedly lower than either E6010 or E6011, but this factor enables it to be used on joints where 'fit-up', is poor and deep penetrating rods would tend to burn through. For this reason also it is good for the welding of sheets and all light gauge material. Undercutting is rare.

It is often used to advantage for welding low-alloy steels and those of relatively high carbon since the admixture with the parent metal, or what is called 'pickup' is low due to little penetration. Consequently the weld is not unduly affected by carbon or other hardening alloys. The lower heat input of this rod reduces distortion to a minimum.

The rod is quite easy to handle in any position, has a fairly high burning speed combined with low spatter loss and is very economical. It is not surprising, therefore, that this type accounts for a very large proportion of electrodes consumed. A cup is rarely formed in the rutile type, and there is a slight tendency to sticking if the arc is held too short. Decomposition of the coating during welding is rare even at high current densities.

With all these assets one might assume that it could be adopted as a universal rod. Unfortunately the physical properties of the weld metal are the poorest displayed by any heavily coated rod. Porosity is quite common, particularly in the root of the fillet welds, and the elongation is rarely above 22% in 2". These physical properties and the lack of deep penetration prevent it being used with confidence on weldments and structures where fatigue stresses are anticipated. However, for structural work and weldments where loads are purely static, it is reasonably satisfactory. It is excellent for building up mild steel shafts, fabrication of sheet metal, machinery, tacking, general repair work, etc.

E6013 (Spot color - brown)

Consumption of this type has steadily increased with the use of A.C. welding. The coating is usually thicker than that on the E6012 rod and may be tan or brown in color often with a reddish hue. Because of the relatively high cellulosic content of this rod, rutile is present in larger proportions in order to produce steady operation when the current is in the reverse polarity phase of the alternating cycle. Ionization of the arc atmosphere to facilitate easy striking and maintenance of the arc under all conditions is achieved by additions of potassium bearing compounds, such as potassium titanate and potassium feldspar.

The rod can be held very close to the work, spatter loss is very low and the metal flows smoothly across the arc in any position.

The slag produced is slightly heavier and slower freezing than the E6012 type, but it is still satisfactory for all position welding. Slag removal is almost perfect, in many cases peeling itself from the weld deposit. Beads are flat, shiny and evenly rippled, having straight clearly defined edges.

In depth of penetration, most physical properties and uses, this type is almost identical with the E6012 electrode. Ductility is somewhat improved by the higher cellulose content, elongation in 2" being in the region of 22 - 24%, although most codes require a minimum of only 17%. High current densities are not recommended because of coating decomposition. Low alloy high tensile steels are ideally welded with this electrode as pickup from parent material is sufficient to increase the tensile strength to that required in the finished weld. Root porosity in fillet welds made with this type of electrode is virtually eliminated and it is well suited for single pass welding.

E6014 and E7014 (Spot color - brown)

These electrodes are essentially of the E6012 and E6013 types with the addition of iron powder. The amount of coating and the percentage of iron powder in the coating are usually less than those of an E6024 electrode (later described). They are not quite as fast as E6024 in the flat position but are faster than E6013. Slag removal is usually better, arc characteristics smoother and less sticking occurs with the small sizes than with similar sizes of E6013. The bead appearance is improved, the deposition rate is higher than E6013 but it is not as high as obtained with an E6024 electrode. The amount and character of the slag permits the E6014 electrode to be used in all position welding, and it is therefore more versatile than the E6024 electrode.

The E6014 electrode is suitable for welding mild and low alloy steels. Penetration is approximately the same as E6012, which is advantageous when welding over gaps due to poor fit-up.

E6015 (Spot color - red); E6016 (Spot color - orange)

These electrodes are a relatively recent development. They represent a great step forward in the welding of steels heretofore regarded as being "hard to weld".

The welding of steels containing more than 0.30% carbon, or small proportions of alloying elements such as molybdenum, chromium, nickel, etc., without special pre-welding and post-welding heat treatment usually resulted in cracks developing in the bead, under the bead, or in the base metal zone immediately adjacent to the bead. Even with low carbon steel of heavy section such cracks were not uncommon and were particularly dangerous under conditions of low temperature.

The theory was advanced after much investigation that this cracking was due, in part at least, to the presence of hydrogen trapped in the weld metal or zones immediately adjacent to the weld metal. With this theory in mind, flux coatings were developed which contained little or no hydrogen bearing compounds. The main constituent is lime with smaller

proportions of fluorspar and ferro alloys for deoxidation. As a consequence, underbead cracking is almost completely eliminated and the possibility of failure originating at such micro-cracks is much reduced*.

In addition these electrodes can be used to advantage for welding medium carbon, low alloy and sulphur bearing steels with little chance of cracking, porosity or surface pinholes. The physical properties are excellent as shown below:

AS WELDED CONDITION

Maximum tensile strength	68,000 to 76,000 p.s.i.
Elongation in 2"	22-35%
Izod Impact	70-130 ft. lbs.

Stress relieving has little effect on these properties.

This type is very useful in maintenance work where the composition of material to be welded is frequently unknown. Because of the absence of hydrogen in the weld metal, deposits can be vitreous enameled and baked without gas evolution spoiling the finish. High carbon, spring steels and armour plate have also been welded with this rod, but in many such cases careful heat treatment is also carried out to prevent cracking.

These low hydrogen or lime ferritic electrodes require different handling to most mild steel rods, in that the arc is somewhat hesitant; higher current densities are required for suitable operation and whipping techniques are not recommended.

Penetration is medium, and there is no tendency for undercutting.

In the vertical position the slag appears quite fluid and heavy, and the maximum core diameter recommended for this position is 5/32". A smooth evenly rippled bead is produced in all positions, spatter loss being very low and the slag not too easily removable. A deep cup of coating is formed during welding, and the rod can be held touching the work without danger of snuffing.

For the E6015 type, D.C. with reverse polarity is used. E6016 can be used with A.C. It contains potassium compounds to promote ionization and arc stability and its general properties are identical with those of E6015, which it has largely superseded.

Very frequently preheating of low alloy steels or heavy sections of mild steel may be avoided by the use of these electrodes with equally satisfactory results.

Caution must be observed to ensure that the rods are properly stored and used in a dry condition as otherwise they lose their beneficial low hydrogen qualities. The manufacturers' recommendations should be strictly adhered to.

* See also Detrimental Action of Moisture and Hydrogen.

E6018 and E7018 (Spot color - black)

This type of electrode has a coating containing a high percentage of iron powder in combination with low hydrogen ingredients similar to those commonly used in E6015 and E6016. As a rule, the coatings of these electrodes are slightly thicker than those of the E6015 and E6016 type. The iron powder in the coating usually amounts to between 25 and 40 percent of the coating weight.

These are D.C. reverse polarity and A.C. electrodes of low hydrogen type. Highest speeds are obtainable with D.C. They are designed for the same applications as the E6015 and E6016 electrodes. In common with all low hydrogen electrodes a short arc should be maintained at all times.

In addition to their use for mild steel, the E6018 and E7018 electrodes are well suited for fillet welds in high strength high carbon or alloy steels. The fillet welds made in the horizontal and flat position are slightly convex in profile, with a smooth or finely rippled surface. The electrodes are characterized by a smooth quiet arc, very low spatter, low penetration and can be used at high lineal speeds.

E6020 (Spot color - green)

All the types discussed so far have been suitable for welding in all positions. The E6020 electrode is limited by the volume and nature of its slag for use in two positions only, horizontal and downhand. The rod operates equally well on direct or alternating current, straight polarity being preferred on D.C. because it produces a flatter bead contour.

Generally referred to as mineral coated, this rod has a heavy coating usually black or red in color, depending on which iron oxide predominates in the coating. Although it is manufactured in all the standard diameters, by far the greatest proportion consumed is in the 3/16", 1/4" and 5/16" diameters. These three sizes are nearly always produced in 18" lengths.

The heavy coating, composed mainly of iron oxides, manganese oxides and siliceous materials, provides a mechanical shield of molten slag to guard against oxidation in the arc. This slag is very slow freezing, permitting the escape of gases from the freezing weld metal and holding in solution any oxides formed in the arc atmosphere. When solid, the slag is usually shiny black and extremely porous. This porosity makes it very friable and easily removable. Its fluid nature and wetting power influences the freezing weld metal forming a concave bead, whose edges are flared into the plate.

In depositing horizontal fillets at high amperages, there is a tendency to undercut the vertical plate, but this can be overcome by holding the rod at an angle of 60° to the horizontal plate.

Penetration with this class is good and can be increased by the use of high amperages. The coating will withstand exceptionally high temperatures without signs of deterioration.

The weld metal has excellent physical properties, elongation in 2" being in the region of 30%. Porosity is negligible and most joints fabricated with E6020 rods are perfect under X-ray examination.

For fabricators with positioning equipment, this is a most suitable rod to use. Deposition rate is high, weld quality is excellent, arc stability is good and spatter loss is low.

It is used on heavy weldments, such as machine bases, center sills on railway cars, pressure vessels, pressure piping, etc. where the operation can be done in the flat or horizontal position. Operator fatigue is reduced considerably under these conditions and efficiency is at its highest.

E6024 and E6027 TYPE

A type of electrode whose use is constantly increasing is one in which iron powder forms an appreciable percentage of the coating. This iron powder fuses along with the coating and deposits as weld metal with the result that these electrodes are very fast. The coating is naturally thicker, which in some instances may make it more difficult to reach the root of a joint. Under such circumstances the joint may have to be opened up or a smaller electrode employed for the initial run. Nevertheless the speed should still be greater.

These electrodes are for use in the downhand or close to downhand position.

The following descriptions are those of the American Welding Society as given in their Tentative Specifications for Mild Steel Arc-Welding Electrodes A5.1-58T.

E6024 (Spot color - yellow)

The E6024 classification of electrode has a covering containing a high percentage of iron powder in combination with fluxing ingredients similar to those commonly found in E6012 and E6013 electrodes. The iron powder fuses along with the core wire and the rest of the covering ingredients as the electrodes melt down and it deposits as weld metal, just as does the core wire material. This increases the deposit rate. The result is that electrodes with iron powder in the covering are the fastest depositing of any type produced.

As a rule, the coverings on E6024 electrodes are very heavy, usually amounting to about 50% of the covered electrode weight. The core wire is identical to that used in E6010 or E6012 electrodes.

Due to the thick covering and deep arc cup produced, the E6024 electrodes are used more extensively with the covering in contact with the parts being welded, i.e., with a "drag" technique. This consists of keeping the electrode covering in contact with the workpiece (both legs of fillet welds) at all times, which makes for exceptionally easy handling. However, sometimes an open arc technique is preferable in groove welding.

The E6024 electrode is well suited for fillet welds in mild steel. The welds are slightly convex in profile, with a very smooth surface and

extremely fine ripple approaching the appearance of machine-made welds. The electrode is characterized by a smooth quiet arc, very low spatter, low penetration and can be used at high lineal speed.

This classification operates with A. C. or D. C., either polarity. The E6024 electrode although most generally used on mild steel, also produces satisfactory welds on many low alloy, medium and high carbon steels.

While originally it was possible because of the conductive nature of the coating on this type of electrode to strike the arc through the coating in practically all cases when the electrode was hot and in some cases when the electrode was cold, further developments which are now available on the market from several manufacturers provide an electrode where the coating is insulated both hot and cold, but where the restriking characteristic has been retained.

E6027 (Spot color - silver)

The E6027 classification of electrode has a covering containing a high percentage of iron powder in combination with fluxing ingredients similar to those commonly found in E6020 electrodes. The iron powder fuses along with the core wire and the rest of the covering ingredients as the electrodes melt down and it deposits as weld metal, just as does the core wire material. This increases the deposit rate. The result is that electrodes with iron powder in the covering are the fastest depositing of any type produced.

As a rule, the coverings on E6027 electrodes are very heavy, usually amounting to about 50% of the covered electrode weight. The core wire is identical to that used in E6010 or E6020 electrodes.

Due to the thick covering and deep arc cup produced, the E6027 electrodes are used more extensively with the covering in contact with parts being welded, i.e., with a "drag" technique. This consists of keeping the electrode covering in contact with the workpiece (both legs of fillet welds) at all times, which makes for exceptionally easy handling. However, sometimes an open arc technique is preferable in groove welding.

The E6027 electrode is designed to produce satisfactory fillet or groove welds in the flat position with A. C. or D. C., either polarity and will produce flat or slightly concave horizontal fillet welds with either A. C. or D. C., straight polarity.

This classification has a spray type metal transfer and deposits metal at high lineal speeds. Penetration is medium and spatter loss is very low. The covering on this type produces a heavy slag, honeycombed on the under side, which covers the weld deposit and is quite friable and easy to remove, particularly in deep groove joints. Consequently, because of the wash-in of the weld metal, combined with the ease of slag removal, X-ray quality welds are readily made in deep groove joints in very heavy sections.

Welds produced with the E6027 electrode have a flat to slightly concave profile with a smooth fine even ripple and with good metal wash up

the sides of the joint. The weld metal possesses excellent radiographic quality. Current ranges for the various diameters are higher than for all other classifications. These higher currents can be used since a considerable portion of the electrical energy passing through the electrode is used to melt the covering and the iron powder contained therein. The E6027 electrode is gaining rapidly in recognition in the pressure vessel and structural field and at this point it has practically replaced E6020 and E6030 electrodes for this particular type of work.

E6028 and E7028 (Spot color - black)

The E6028 electrode is in many respects very much like the E6018. The E6028 differs from the E6018 (and the E7028 similarly from the E7018) in the following respects:

1. The E6018 is an all position electrode; whereas, the E6028 is suitable for horizontal fillet and flat position welding only.

2. The coating of the E6028 electrode is much thicker than that of E6018; the coating of E6028 electrodes represents approximately 50% of the weight of the electrode. The iron content of the E6028 coating is higher than that of the E6018. As a consequence, in horizontal fillet and flat position welding the E6028 gives a higher deposition rate than the E6018 for any given size of electrode. The iron powder content of the E6028 coating represents about 50% of the weight of the coating.

3. The E6028 has a spray type transfer; the E6018, a globular type transfer.

4. The ratio of the weight of the weld metal to the weight of the core wire consumed is about 1.05 minimum for the E6018 and about 1.30 minimum for the E6028.

Apart from the above differences, all that has been said about E6018 and E7018 electrodes applies equally as well to the E6028 and E7028 types.

E6030 (Spot color - violet)

This type is very similar to the E6020 except that its use is limited to the flat position. Operation is good on A. C. or D. C. and deposition efficiency is usually slightly higher than the E6020 type. The main ingredients are the same, but the wetting power, fluidity and freezing range of the slag differ somewhat by the addition of oxides and silicates of aluminum, magnesium, etc.

The effect of these adjustments is to produce a slag which washes well up against the side walls of the weld groove and offers little danger of slag entrapment along the groove faces.

The physical properties obtained are equal to, if not better than those of the E6020 type and deposits are usually perfect under X-ray examination.

Some versions of the E6020 type so closely match E6030 performance that most manufacturers have discontinued production of E6030.

LOW ALLOY STEEL ARC WELDING ELECTRODES

From the foregoing the student will have learned that the E70 - E120 series are low alloy electrodes for the welding of low alloy high tensile steels. They are classified on the basis of the mechanical properties of the stress-relieved deposited weld metal, type of coating, welding position of the electrode and type of current as well as chemistry of the deposited metal. They are similar in characteristics to the E60 series and their additional strength is usually obtained through the addition of alloying ingredients from the coating.

There are, however, as already mentioned, electrodes available in the E70 class which are not of the low alloy type, i.e. E7014, E7015, E7016, E7018, E7024 and E7028. They are of sufficiently high tensile strength to meet the requirements of 70 Class type rods despite the fact that they are of mild steel composition. The AWS and CSA codes make allowance for this by providing that any mild steel electrodes that meet the E70 Class specification can also be rated as an E60 Class of the same type.

Molybdenum is the most common alloy addition, and many electrodes in the E70 series deposit metal containing from 0.4% to 0.6% of this element. For the E80, E90 up to E120 series the molybdenum content may be increased and also additions of nickel, chromium and manganese up to 2% used to give high tensile strength combined with satisfactory ductility.

Minimum tensile strength requirements for stress-relieved all-weld-metal tension test specimens made with E70 - 120 types are in the range 70,000 to 120,000 p.s.i., as indicated by the first two or three figures in the electrode classification number. Elongation in 2", min. percent, is in the ranges: E70 - 22 to 25%; E80 - 16 to 19%; E90 - 14 to 17%; E100 - 13 to 16%; E110 - 15% and E120 - 14%.

Since the principal distinction between electrodes in any of these higher series is in their tensile strength and since such strength may be obtained through the addition of alternative alloys, it follows that the chemical composition of the deposited metal of similarly classified electrodes may not necessarily be the same.

If therefore such metal is required to resist corrosion or elevated temperatures, or both, some care must be exercised in choosing electrodes not only on the basis of their strength but on the chemical composition of the deposited metal (see Table 5.12 - Chemical Requirements).

It is natural to try to duplicate the parent metal but since some alloying elements cannot very effectively be transferred through the arc, others may be accepted providing they produce equivalent or nearly equivalent results. In certain cases where transfer of an element from the coating is not satisfactory, transfer may be achieved by using a core wire containing the necessary alloy.

Preheat and interpass temperatures for the electrodes with

letter suffixes A_1 and B_1 (see Table 5.12) are in the ranges 200 to 225°F. or 325 to 375°F., depending on chemical composition of the deposited metal. Stress relief temperature is 1150 ± 25°F. For electrodes with letter suffixes B_2, B_3 and B_4 preheat and interpass temperatures are 325 to 375°F. and stress relief temperatures 1275 ± 25°F.

Typical applications for low alloy steel electrodes are fabrication of high strength light weight weldments, piping for high temperature and pressure service, diesel engine frames, aircraft assemblies, oil refinery equipment and repair of high strength castings.

CHOOSING AN ARC WELDING ELECTRODE

All the electrodes in the E60 classification are made for specific purposes and have distinctly different characteristics. Therefore in order to be able to decide which is the most suitable and economical electrode to be used on any particular type of work, the various characteristics must be understood, particularly in relationship to other electrodes in the series. Since the E60 series is representative, it will be discussed in detail and an endeavour will be made to tabulate the various electrodes on the basis of their operating characteristics, weld quality and cost factors.

It should be understood that although all approved electrodes of all manufacturers meet the minimum requirements of their classification, they are not necessarily identical. One may emphasize one characteristic and one another. Thus the user has a range of choice within a classification.

Operating Characteristics

Penetration -

This is the term used to describe the ability of the arc of a given electrode to penetrate into the parent metal. It is largely dependent on the concentration of the heat in the molten pool. With bare wire electrodes the majority of the heat will be liberated at the positive terminal, and to obtain maximum penetration it is usual to make this the work. With certain coatings this condition may be entirely reversed so that the most heat is liberated at the negative pole and in such cases it is customary to make the work negative. With A. C. equal heat is liberated at each terminal. The degree of penetration is also dependent on the amperage used.

Arc Force -

This is another way of describing the penetrating ability of an electrode. It is the ability of the arc to dig into the parent metal and force the molten parent and electrode metal to become displaced and form into a bead immediately to the rear of the crater. Some electrodes are designed to concentrate this arc force and dig deeply while others produce a soft arc and provide a wide shallow crater.

Undercut -

A groove melted into the base metal adjacent to the edge of the weld and left unfilled. Always an undesirable feature.

Ease of Handling -

The ease with which the arc may be maintained, and the slag and molten metal controlled, together with the general ability of the electrode to operate satisfactorily over a wide range of conditions of arc length, current, speed of travel, etc.

Although listed in Table 5.13 under operating characteristics, ease of operation is also a cost factor since the efficiency of a welder varies directly with the ease of operation. Where a rod is difficult to handle and the position is overhead, we can expect much lower arc time than when a heavy coated rod is being deposited on a positioned weldment. As has been previously noted, arc time as a percentage of actual welding time can vary from 20 to 80% depending on the type of work.

Ease of Striking and Re-Striking -

The ability of the electrode to quickly establish and maintain an arc upon being touched to the work. Ease of re-striking is determined not only by the electrode coating but by the distance to which the coating extends over the burned end of the electrode, the amount of slag which solidifies over the end of the electrode, and the thickness of the electrode coating.

The re-striking characteristics of most iron powder type electrodes is such that a portion of the coating cone has to be heated up by electrical resistance before the arc is established and thus, while it is easy to re-strike in the sense that you do not have to break away the coating, nevertheless the E6010 or E6012 type of electrode with the thinner coating will re-strike much faster. This is accomplished by the fact that when the electrode is touched to the work the thinner and more fragile coating breaks exposing the core wire, but nevertheless the re-striking is more instantaneous than that of the E6024 or E6014 type.

Poor Fit-Up -

The ability of the electrode metal to bridge a gap at welding currents which are not exceptionally low.

Light Gauge Plate -

This indicates the ability of the electrode to operate at high speeds on light gauge plate without burning through.

Overhead Usability -

This is determined by the viscosity of the weld metal and slag which allows metal to be deposited in the overhead position easily and without excessive loss.

Vertical ~~Up~~ -

This indicates the ability of the electrode to weld vertically upwards, i.e. from the bottom to the top of the joint, using either a weaving or 'weld and run' technique.

Vertical Down -

The ability of the electrode to weld vertically downwards, i.e. from top to the bottom of the joint without excessive weaving.

"Weld Quality"

Tensile Strength -

This is the maximum tensile load in pounds per square inch that the weld metal will resist before ultimate failure.

Ductility -

This is the ability of the weld metal to deform or stretch without breaking; it is usually measured on a tensile test piece as 'elongation' in 2 inches or 8 inches (depending upon the test being made) and is expressed as a percentage, e.g. 25% in 2" indicates that the original 2" length stretched to 2-1/2" during the test. Various diameters are used for the test pieces. A complete specification of test piece diameter, percentage elongation and the distance over which it is measured is necessary for any comparison of elongation to be satisfactory.

Impact Value -

This test is used to ascertain the resistance to fracture of a rigidly held notched metal specimen when subjected to a blow from a swinging hammer or pendulum. The value of this resistance is expressed in foot pounds.

The Sensitivity of the Electrode to Plate Composition -

This is also an important factor as regards weld quality, and Table 5.13 indicates the degree to which the various electrodes will react with the parent metal. Since the parent metal may contain high proportions of some detrimental elements, the effect on quality will be understood.

Bead Contour -

Different welding positions and different electrodes affect the shape of the weld bead. This is an especially important factor in fillet welds.

Soundness -

This indicates the extent of porosity or slag inclusions in the deposited metal.

"Cost Factors"

Slag Removal -

The ease with which slag may be removed from the completed weld.

Spatter Loss -

This is the term used to describe the extent to which metal particles are thrown out of the arc during welding and wasted.

Under normal operating conditions, spatter loss varies from 8 to 12% of the electrode weight and can become even higher if excessive currents or poor procedures are used. Shorter arc lengths, welding sequences to avoid arc blow, and use of correct currents are recommended to keep spatter loss at a minimum. The loss is greatest with the E6010 type and least with the E6020 type as will be noted from Table 5.13. Generally speaking, medium penetration rods have lower spatter losses and therefore greater efficiency, giving a longer weld per electrode.

Current Capacity -

The capacity of the electrode to carry high currents in order to facilitate faster working without detrimentally affecting its operating characteristics or the quality of the weld metal.

Deposition of metal, from any given electrode, increases with current density. As an example let us take a 1/4" electrode of the E6020 class:

WELDING CURRENT (AMPS)	POUNDS/HOUR OF ARC TIME
240	5.5
320	7.0
400	8.7

While high current densities are suitable for mineral coated rods, it should be remembered that cellulosic coatings deteriorate at higher temperatures and care should be taken in determining maximum current settings for E6010, E6011 and E6013 type coatings.

Steel to Flux Ratio -

This is the ratio between the weight of the core wire and the weight of the flux coating. As electrodes are sold by the pound, the less flux the better since more metal will be available for deposit in, say a fifty pound box of electrodes.

Deposition Efficiency -

The proportion of weld metal usefully deposited in relation to the weight of electrode consumed - usually expressed as a percentage.

Deposition Rate -

The rate at which weld metal is deposited - usually expressed in pounds per hour. Incidentally it should be understood that deposition rate and speed of travel are not the same thing. Between any two electrodes, a practical test will generally show which has the highest rate of travel.

Although the heavier coated electrodes usually have a higher rate of deposition, the cost of these electrodes per pound of deposited metal is higher because of the high flux coating loss. The following figures show the weight of various types of electrodes required to deposit 10 pounds of weld metal:-

TYPE	WEIGHT OF ELECTRODES REQUIRED
E6010	15.75 lbs.
E6012	16.0 lbs.
E6020	21.0 lbs.

Electrode Length -

Although not possible to tabulate in Table 5.13, electrode length is also a cost factor. Where practicable, maximum length is recommended, because stub end loss per foot of weld is reduced. Normally stub end loss averages 17% of electrode weight. By using 18" lengths instead of 14" lengths a saving of approximately 3% in electrode cost can be effected.

This represents 10 rods in a 50 lb. box of 1/4" electrodes. Of course the time lost in electrode changing is also reduced. However, it should be understood that longer electrodes will heat up more, with possible deterioration of the coating, if high current values are used. This is particularly true of those with coatings of a high cellulose content such as E6010.

These then are the principal points which must be considered when selecting electrodes in order to obtain the one which is the most suitable and economical.

An Example of Electrode Selection -

In order to select an electrode, the job for which it is being chosen must be carefully considered, and at least five or six of the most essential characteristics listed.

As an example of such consideration let us take the fabrication of a heavy excavator frame or base of 0.25 to 0.30% carbon plate.

Although perhaps unusual in a shop where such work is performed, we will assume that no positioning equipment is installed and therefore an all position electrode must be used. Also, only A.C. is available.

From the nature of the job and anticipated service we can also assume that:

1. The frame will be subject to fatigue and alternating stresses and therefore sound weld metal of high impact and ductility values will be highly desirable.

2. Since the plate is fairly high in carbon, an electrode low in sensitivity and of low or medium penetration would be best.

3. Good fit-up may be anticipated.

4. A straight to concave fillet contour will be best for fatigue stresses.

5. Good bead appearance is of course desirable but not really important.

6. Low electrode cost is to be desired but is relatively insignificant in a job of such importance and high over-all costs.

Since an electrode high in impact value is desirable, this would lead the selector to E6018, 6016, 6014 or 6011. Minor cost factors would favour both E6012 and E6013 about equally. Both would have a smoother bead than E6011 and between the two E6013 would have a better finish and contour.

However in a job of this type weld qualities of impact, ductility and soundness must be given preference and the choice will fall on type E6016, E6014 or E6018 (see Table 5.10).

Another convenient approach to the selection of electrodes is to classify them under the following easy to remember categories which have come into fairly general usage recently:

(a) Fast Fill

(b) Fast Follow

(c) Fast Freeze

(d) Weldability

These terms can be defined as follows:

Fast Fill -

For certain fillets, laps and deep grooves of a definite size, such that it takes a definite amount of weld metal to fill the welds up to their proper size, the problem is to deposit the required weld metal in the shortest possible time. The answer to the problem is to select an electrode with a high deposition rate such as the iron-powder electrodes.

Fast Follow -

When the size of the weld can be made smaller in order to get higher welding speeds, then an electrode with fast follow characteristics is used. This amounts to taking a given quantity of weld metal and spreading it thinly over a long length of joint in a very short time. To do this the molten metal crater must have the ability to follow the electrode at relatively fast travel speeds. An extreme case of fast follow welding with hand electrodes is the lap welding of automobile frames, which can be accomplished at the rate of 60 inches per minute, and where it is not uncommon

to weld 48 inches of joint with one electrode. Many of the Fast Follow applications are on sheet metal and the best electrodes for these applications are the 3/16" and smaller sizes of the E6012's.

Fast Freeze -

Vertical and overhead applications require, for ease of welding, that the weld metal solidify or freeze quickly. For these applications E6010 electrode is the best answer.

Weldability -

Some steels are high enough in sulphur, carbon or phosphorus to require special consideration in the choice of electrode to produce crack-free welds. Heavier thicknesses of steel also present a problem because of the severe quenching of the welds. This severe quenching may result in cracks. The first consideration in welding these steels is the selection of an electrode which will produce crack-free welds. High welding speeds and ease of welding are of secondary importance here. The low hydrogen E6015 or E6016 would probably be the choice.

STAINLESS STEELS

To understand stainless steel electrodes, it is first necessary to understand stainless steels - their characteristics, composition, uses and behaviour when subjected to welding heat. They are therefore introduced at this point.

What are stainless steels ? Stainless steels are simply steels which have one characteristic in common. They are all highly resistant to corrosion and oxidation. This means they have a marked ability to withstand being attacked, dissolved, or eaten away by a large number of chemicals, liquids and gases being used in industry today. This highly desirable property of resistance to corrosion is due to their containing the element chromium. We usually think of stainless steel as containing a minimum of 10% chromium; however, the 4% to 10% chromium steels also offer resistance to corrosion.

The reason for the protection given these steels by chromium may be partially explained in this manner. The oxygen in the atmosphere, and other corrosive media, attack all metals. Oxidizable metals attempt to protect themselves by plating their surfaces with an oxide, or thin film. In the case of iron and steel, the oxide is iron oxide, or rust; with aluminum it is aluminum oxide, and with stainless steel it is chromium oxide.

The oxide which forms on iron or steel is loosely adhered and easily broken away. Therefore, the oxide continues to form and be broken away over and over again until the oxide, or rust, has eaten away the metal.

With aluminum the oxide is more stable and offers more protection so you have a metal which resists further attack and which will last for years.

The chromium in stainless steel forms a colorless, close,

tight and continuous oxide film over the surface of the metal. This film is stable and gives high resistance to further oxidation or corrosion of the metal.

Most stainless steels in use today in any volume have been given designations by the American Iron and Steel Institute (AISI) and include a number of different classifications or groupings, such as the "300", "400" and "500" series. The 500 series is neither strictly stainless nor heat resisting, but is conveniently grouped with the others as it has a higher chromium content (5%) than any of the low alloy high tensile steels. It is used largely in the oil industry due to its resistance to the corrosive attack of crude oils. Unlike those of the 300 series it hardens very readily and requires both preheat and postheat for welding.

Electrodes suitable for each of these series are given the same group number which is prefixed by the letter E as for mild steel to indicate an electric arc welding electrode. Thus we have the E300; E400 and E500 series of electrodes. Fortunately it is not necessary to have an electrode for each of the various steels of these series, as the composition of one electrode is often suitable for several. Thus E308 which is suitable for steel 308 may also be used satisfactorily to weld types 301 to 308 inclusive.

While all stainless steels possess the common ability to resist corrosion, the degree to which they exhibit this resistance varies considerably. This degree is controlled by a number of variables, of which three of the most important are:

1. The ability to resist corrosion is proportional to the amount of chromium in the steel. The higher the chromium content, the more resistant the steel is to corrosion.

2. The amount and types of other elements present.

3. The heat treatment to which the metal is subjected during welding, or the temperatures at which the finished unit must be used after welding.

The ability to resist corrosion is proportional to the amount of chromium in the alloy mixture - this is a good general rule to follow. However, the other two variables must be taken into consideration.

For example, additional elements such as nickel, columbium, titanium, molybdenum, silicon, and others, are frequently added to impart certain desirable properties. Some of these alloys improve the ability to withstand corrosion at high temperatures or when in contact with a particular corrosive media. Others make the steel more readily workable, machinable, or add to other physical properties. These alloys may increase the ability a steel has to resist corrosion, they may not affect this property at all, or they may detract from it.

The effect of heat during welding and the effects of operating temperaturesof the manufactured stainless steel units will be discussed later.

Classification of Stainless Steels

Metallurgically, stainless steels are classified as:- 1. martensitic, 2. ferritic, or 3. austenitic. Before further discussion, we should get some idea of what these three words mean. For simplicity we will not go into metallurgical definitions but will discuss some of their properties.

Martensitic Class -

This is the straight-chromium type of stainless (containing chromium as its principal alloying element) and is normally HARD and BRITTLE. This stainless steel is of the air-hardening type. When welding, preheat and postheat should be used. This class includes the 4% to 10% chromium types. This class is magnetic.

Ferritic Class -

This is also of the straight-chromium type. Normally, it is SOFT and DUCTILE but may become brittle when subjected to welding temperatures. When welding on this type, preheat and postheat should be used. This class is magnetic. It includes the 12% to 28% chromium types.

Austenitic Class -

This steel is of the chromium-nickel type. The nickel content usually ranges from 7% to 35% with 8% to 10% being the most predominantly used. It is STRONG, DUCTILE, and RESISTANT to IMPACT, thus striking a medium of the desirable properties of both of the straight-chromium types. This class is non-magnetic in the annealed condition but is slightly magnetic when cold-worked. No preheat or postheat is necessary when welding this class of stainless steel.

The different types under each of these classes of stainless steels represent a wide variety of chemical compositions, each with its own particular properties, or characteristics. Knowledge of these individual pecularities of the various stainless steels is necessary to you in order to select the correct type of electrode for a specific application and to ensure manufacture of your product in the most efficient manner possible.

The Effect of Heat on Chromium-Nickel Stainless Steels

All those acquainted with steel know that heat has various effects upon steel's properties. They also realize that successful work rests upon a full knowledge of what happens to the steel when subjected to the heat of the welding arc.

With mild or low-carbon steel, the operator's chief concern is with mechanical properties. Stainless steel includes not only these factors but also the effect of heat upon the corrosion resisting strength. Also, the effect of heat on the metallurgical reactions of stainless is different in some respects from that of mild steel. As an example, if you heat mild steel to 1600-1900° F. and quickly quench, such as by immersion in water, you will secure maximum hardness. If you treat an austenitic or chrome-

nickel steel (such as 308, 309, etc.) in the same manner you will secure maximum softness.

You often hear it said that lower heats or currents must be used when welding with stainless steel electrodes. It is also said that stainless steel plates buckle or warp much easier than plain steels. Is this true ? And if so, why is it true ?

Perhaps the following statements and accompanying charts will aid in better understanding the effects of heat on stainless steel.

Referring to Figure 5.1, the electrical resistance of stainless steels is much greater than is the resistance of mild steels. The more resistance a metal offers to the passage of electric current, the quicker the metal will melt. Therefore, less amperage will be needed.

Figure 5.2 shows that the melting points of stainless steels are somewhat lower than are the melting points of mild steels. Therefore, less heat or amperage is required to melt them.

Figure 5.3 compares the thermal conductivity or rate of heat transfer of stainless steels to that of plain steel. The lower values for stainless steels mean that they retain heat for longer periods of time because heat is not conducted away as fast.

Figure 5.4 shows that coefficient of expansion, or magnitude of expansion, of austenitic stainless steels is much greater than that of plain steel, so warpage or buckling may be worse than with mild or straight-chromium types. The expansion of straight-chromium types is very close to that of plain steel.

To study Figures 5.1 through 5.4 will give some understanding of the heating problems encountered in the fabrication of stainless steels and thus make it possible to eliminate many welding difficulties.

Most of the effects of heat which we have been discussing are effects on mechanical properties. Let us now consider the metallurgical changes which take place in stainless steels when subjected to the heat of the welding arc.

In welding of austenitic stainless steels, one of the most predominant metallurgical problems encountered is that of carbide precipitation. It is sufficient, at this point, to say that carbide precipitation causes the stainless steel to lose its corrosion resisting properties in the areas affected. When this loss is due to welding, it will be noticed by corrosion in the heat affected zone near the weld deposit. These zones have been "robbed" of their chromium.

Figure 5.5 shows the effect of welding of an unstabilized base plate with an unstabilized electrode. If another weld were made crossing the weld bead shown, the latter will react as part of the unstabilized base plate and thus the heat affected zones resulting from this second weld would be subject to carbide precipitation. Therefore, it is necessary to employ both an electrode and base plate which are stabilized, or to increase the cooling rate as discussed below.

The temperature range, known as the carbide precipitation range, is from 800°F. to 1550°F. The peak of the danger zone is at about 1250°F. The extent of the carbide precipitation is determined by (1) the amount of carbon in the base metal or metal deposited - (2) the critical temperature range of 800°F. to 1550°F., and (3) the time the metal is held in this critical temperature range.

Students should be familiar with three possible ways of reducing or eliminating the problem of carbide precipitation. First by using stabilized base plate material and an electrode which has had stabilizing elements added to the coating or core wire and which will deposit these elements in the weld deposit. Second, by the use of extra low carbon (ELC) base plates and an ELC electrode which gives a weld deposit low in carbon. Third, by increasing the cooling rate of the weld zone through the carbide precipitation temperature range. (See discussion below).

Both stainless steel plates and electrodes for welding these plates are manufactured today with elements added which aid in the stabilization of carbon, thus reducing or eliminating carbide precipitation.

Columbium (Cb) and Titanium (Ti) both have a stronger affinity for carbon than does chromium. Thus they tie up the carbon present and leave the chromium free to stay distributed throughout the metal and do its important job of giving the metal high resistance to corrosion.

Stabilized electrodes (such as E347, 309Cb, or 310Cb, etc.) are stabilized by addition of the element columbium to their coatings. Although titanium is also a very good stabilizer, it is not used in electrodes because it will not transfer across the welding arc. Therefore, when welding on a base plate which has been stabilized with titanium, an electrode stabilized with columbium must be used.

Base plates and electrodes with extra low carbon (ELC) content are also available. The thinking here is that if you have less carbon in the plate and deposit to begin with, you will have less trouble with the formation of chromium carbide, which is the compound formed when you have carbide precipitation.

Remember that the critical cooling range is between 800°F. and 1550°F. Below or above this range, no carbide precipitation troubles are encountered. Remember also that the time the temperature of the metal is in this range also has a bearing on the amount of carbide precipitation encountered. Since the rate of heat conduction in stainless is slow, one should aid the stainless to have a faster cooling rate while passing through the critical temperature range.

The following are some ways of doing this:

1. While welding, aid the cooling rate by (a) keeping the heat input down by using small diameter electrodes, lowest current possible, and making stringer beads instead of using weaves, and (b) using chill bars and holding fixtures which will have a cooling effect.

2. Immediately after welding and while weld deposit is still above 1600°F., use air or water quench to below 800°F.

3. If facilities for postheating the manufactured unit are available, heat the unit to above 1900°F. and hold for a period of time to allow the carbide to dissolve. This allows the carbon and chromium to re-enter the solution. This treatment should be followed by a fast cool or water quench to below 800°F. This treatment can be used any time carbide precipitation has formed and you desire to correct it.

If a finished austenitic stainless steel unit is produced for service in temperature ranges of 800°F. to 1550°F. (or exposure to very severe corrosive media), the base plate and electrode must be either of the stabilized or extra low carbon type. The stabilized plates are usually AISI Type 347, stabilized with columbium, or AISI Type 321 which is stabilized with titanium.

If, however, the service requirements are such that the unit will not be used in the critical temperature range, any of the stainless steels and electrodes which meet other requirements can be used. Also, any of the three methods mentioned for reducing this trouble can be used successfully. Here it is only necessary to limit or remove the carbide precipitation due to the welding procedure.

The Effect of Heat on Straight-Chromium Stainless Steels

The effect of heat on the straight-chromium stainless steels (those which have chromium as their principal alloy element) is quite different than it is on the austenitic stainless steels.

First, these stainless steels are not subject to carbide precipation. They are considered stable over the entire temperature range. Thus, their ability to resist corrosion is not affected by the heat of the welding arc.

The effects of heat and cooling rates on these types are chiefly concerned with (1) grain growth - the individual crystals, or grains, of the metal grow larger when subjected to welding temperatures, which causes the metal to become brittle, and (2) hardenability - in the 3% to 18% chromium grades. The metallurgy of the straight-chromium stainless steels is very difficult to cover in detail in a discussion of this type.

As brought out previously, there are two classes of straight-chromium stainless steels: (1) martensitic, which is normally hard and brittle, and (2) ferritic, which is relatively soft and ductile. (However, with ferritic steels welding temperatures may cause them to become brittle.)

These classes can best be discussed by breaking them down into three Groups according to their chromium content: (1) 3% to 14% chromium (martensitic), (2) 14% to 18% chromium (martensitic or ferritic) and (3) 18% to 30% chromium (ferritic).

Martensitic Stainless Steels

Here are facts we know about these Steels, Group (1):

1. They are not subject to carbide precipitation or loss of corrosion resistance when subjected to welding temperatures.

2. They are subject to grain growth when subjected to elevated welding temperatures. This grain growth causes the metal to become brittle. Small grain size CAN be restored by heat treatments. This results in improved ductility.

3. They are subject to air hardening and will harden intensely if allowed to cool in air. When welding, if the proper heat treatments are not followed, difficulty from cracking will be encountered.

4. Preheats and postheats are used for the purpose of slowing down the cooling rate to avoid excessive hardening and to prevent cracking.

5. They respond physically to heat treatment. Therefore, a considerable range of physical and mechanical properties can be obtained from the same type of metal.

6. Type 309 and 310 electrodes can be used for welding in many applications. Using low welding currents with these electrodes may eliminate the necessity for preheat.

7. Metals in this group are magnetic.

The steels containing 2% to 9% chromium are considered useful for service at temperatures to about 900°F. Their most important use is to impart high strength at elevated temperatures. Sometimes, molybdenum is added to these lower chromium steels to further increase their high strengths at elevated temperatures.

The types most often welded in industry are AISI Types 502 (5% Cr), 505 (10% Cr) and 410 (12% Cr).

Some of the many applications for these martensitic (3% to 14% chromium) stainless steels are machine parts, oil refinery equipment, low priced cutlery, pump shafts, bushings, valve parts, bolts and nuts, high temperature pipes, and numerous other high temperature applications.

Intermediate (14% to 18% Cr) Stainless Steels

As you will notice, Group 2, the 14% to 18% chromium types, have been listed as having characteristics of either or both martensitic and ferritic types. These are sometimes spoken of as being in the intermed-

iate zone or class and their metallurgical reaction depends upon the exact relation between the chromium and carbon present.

We could think of these types as taking one of the following metallurgical structures:

1. Those which are sufficiently low in chromium and high in carbon so that they exhibit martensitic properties to such a degree that, for all fabrication purposes, they could be considered martensitic steel.

2. Those which are sufficiently high in chromium and low in carbon that they exhibit ferritic properties to such a degree that, for all fabrication purposes, they could be considered ferritic steel.

3. Those which have a ratio of chromium and carbon so that they exhibit a balance between martensitic and ferritic properties. These are sometimes preferred because soft ferritic constituents may reduce the cracking tendencies of the hard martensitic constituents when used in certain applications.

Following this line of thinking, AISI Type 430 stainless steel and the same type of electrodes, would have a structure as explained under (2) above and could, therefore, be treated as a ferritic steel.

Before attempting to weld, it is advisable to seek confirmation from your supplier as to which type you are having to deal with.

Ferritic Stainless Steels

Let us now look at Group 3, the ferritic steels. We have noted before that this steel is soft and ductile in the normal, or annealed, condition. However, when subjected to the welding temperatures, these steels can become very brittle. A list of the facts we know about these 18% to 30% straight-chromium steels may clear this up somewhat:

1. These are non-hardenable stainless steels. The cooling rate has little or no effect on their ultimate hardness.

2. They are not subject to carbide precipitation and do not lose their ability to resist corrosion when subjected to welding temperatures.

3. They are subject to grain growth when subjected to welding temperatures above 1600° F. and to slow cooling rates from 1200° F.

4. Their brittleness after welding is not due to hardness, rather it is the result of grain growth.

5. Their grain growth, once it occurs, CANNOT be corrected.

6. Grain growth and resulting brittleness, in the ferritic steels, can be minimized by low heat input and avoiding unnecessary heat build-up. This can be accomplished by:

   a. Using small diameter electrodes,

   b. Using low currents,

   c. Allowing weld zone to cool to preheat temperature between stringer beads.

7. Preheat of minimum 300° F. must be used as weld zones and beads of ferritic steels are very brittle below this temperature.

8. When units manufactured from these steels are used for prolonged periods of time in a temperature range of from 800° F. to 1200° F. they may exhibit extreme brittleness on returning to room temperatures. Some of this brittleness can be removed by heating the steel to above 1200° F. and quickly quenching by either air cooling, if the section is of thin sheet, or water cooling, if the section is of thicker metal, to below 800° F. Since ferritic stainless steel cannot be hardened by quenching, you will encounter no difficulty from this.

9. Type 309 and 310 electrodes can be used on ferritic stainless steels to ensure weld deposits with high ductility and impact strengths.

Table 5.14 summarizes the foregoing discussion. It should be used only as a guide in the approach to the solution of problems arising in the welding of straight-chromium stainless steels.

The volume of straight-chromium stainless steel used in industry is much smaller than that of the austenitic or chromium-nickel stainless steels. From the foregoing discussion, it is quite plain that the fabrication problems of straight-chromium stainless make it less desirable in most applications where a choice can be made. However, there are many applications where this steel is superior to the chromium-nickel types. Many fabricators successfully replace the chromium-nickel stainless steels with the straight-chromium types in certain applications.

Common commercial wrought and cast chromium-nickel (austenitic) stainless steels and their welding characteristics are given in Tables 5.15 and 5.16, respectively. These grades are readily weldable by any of the major welding processes. Welding characteristics and recommendations for the common commercial wrought martensitic and ferritic stainless steels are given in Tables 5.17 and 5.18.

STAINLESS STEEL WELDING ELECTRODES

Stainless steel welding electrodes can be broken into two basic

classes: (1) chrome-nickel, and (2) straight chrome. Chrome-nickel can be further broken down according to the type of coating used on the electrode - (a) lime type (using D.C., reverse polarity only) and (b) titania type (using A.C. or D.C. reverse polarity). (See also usability classification).

The lime type produces less slag than the titania type. Deposits are sound, of high strength, with good ductility. The lime type is generally recommended for highly restrained joints where cracking is a problem, for welding in the downhill vertical position and for free machining high sulphur stainless steels - (AISI 303 for example).

The titania type has a very smooth arc and the metal flows easily with practically no spatter. However, a more concave bead and thinner deposit from the titania type frequently causes cracking on heavy stainless steel weldments because there is insufficient weld metal to resist the stresses. On the other hand, the deposit from the lime type coating is more convex and thicker and generally preferred for heavy weldments, particularly the first few passes.

Table 5.19 presents a very comprehensive summary of welding characteristics of commercial stainless steel electrodes, their application and respective heat treatment (if any). Under the column headed "Popular Designation", the first number is an indication of the percent of chromium and the last number the percent of nickel, columbium, molybdenum, etc., or ELC - "extra low carbon".

Tables 5.15, 5.16, 5.17 and 5.18, mentioned above, include necessary data on the steels together with recommendations for electrode selection for any particular wrought steel or casting.

Usability

In order to indicate current requirements as well as suitability of the electrode to weld in various positions, additional numbers are suffixed to series E300 and E400. These suffixes are as follows:-

EXXX - 15	D.C. all position
EXXX - 16	A.C. or D.C. all position
EXXX - 25	D.C. horizontal fillets and flat position
EXXX - 26	A.C. or D.C. horizontal fillets and flat position.

Table 5.20 also shows classification numbers of electrodes for each series including usability designation (-15, -16, -25 and -26), indicating type of current and positions of welding.

This table includes also the E500 series (E502) which is neither strictly stainless nor heat resisting, but is conveniently grouped with the others as it has a higher chromium content (5%) than any of the low alloy

high tensile steels where it might otherwise be found. It is used largely in the oil industry due to its resistance to the corrosive attack of crude oils. Unlike those of the 300 series, it hardens very readily and requires both preheat and postheat for welding.

DETRIMENTAL ACTION OF MOISTURE AND HYDROGEN FROM ELECTRODE COATINGS

Moisture is a component of all electrode coatings just as much as any of the chemicals and should be maintained within certain desirable limits as with other ingredients. This is not easy since some coatings absorb moisture to varying degrees depending on the atmospheric conditions. If a coating takes up excessive moisture, it can be dried, but here again some electrodes fail to function properly if too dry.

The coating of an excessively damp electrode will have a tendency to 'pop' or explode. Often a swelling will be observed just above the arc while in operation. Also, if the electrode is short circuited permitting the welding current to pass through it for a short period, moisture may be driven off as a vapor. This should be only done as a test for moisture and not as a means of drying.

Moisture will have a tendency to produce porosity in the weld, but more important it can break down into hydrogen gas and this can be seriously detrimental to a weld and lead to cracking in or near the weld. These cracks are originally microscopic but may well develop and result in failure. See Figures 5.6 and 5.7.

It is for this reason that low hydrogen electrodes are used and for the same reason it is of the utmost importance that the coatings of low hydrogen electrodes are kept dry and free of moisture.

Considerable research work has been undertaken on the production and effects of hydrogen which can be in part explained as follows.

Hydrogen from the electrode coating is absorbed by the molten metal during the welding process. The solubility of hydrogen in iron diminishes with decreasing temperature, at the solidification point it even drops abruptly. Thus the absorbed hydrogen will be partly released again during the cooling process. The thicker the metal from which the gas is to be released and the lower the temperature, the longer the diffusion process will take. Hence if the metal to be welded is very thick, a large quantity of hydrogen will be retained, in the first place owing to the long distance the atoms have to travel in the diffusion process and in the second place by the rapid cooling caused by the thickness of metal. The presence of sulphur may retard the release of hydrogen still more.

The excess of hydrogen, left in the metal, after the cooling process, can collect under very high pressure (hundreds of thousands p. s. i.) in internal microscopic and sub-microscopic voids. Welding with conventional types electrode may be expected to lead to the building up of large pressure of hydrogen in tiny voids within the weld. Consequently test bars made from the metal of such a weld show so-called fisheyes on the surface of fracture (Figure 5.8, A, B, and C). During the deformation of the test

bar this results in brittle fractures on a very small scale in these regions. It was found that the pressure in the micro voids only increases to dangerously high values during elongation. Hence fisheyes can only be formed after much larger deformation than ever occurs in a machine or structural part and therefore cannot adversely influence the strength of the welded joint.

Figure 5.9 shows the influence of the sulphur content in the base metal as well as moisture in the electrode coating on the weld.

STORAGE OF ARC WELDING ELECTRODES

To obtain the best possible results from arc welding electrodes, it is essential that they should be stored in absolutely dry conditions. This is particularly so in the case of low hydrogen electrodes, which are more hygroscopic than other types, i.e. they readily pick up moisture.

When the storage room fulfils the requirements for keeping low hydrogen electrodes dry, no difficulty will be experienced with the other types of electrodes less sensitive to moisture. A storage room can be made dry in various ways, of which two methods will be described. The first, and most widely used, method is to ensure that the temperature of the storage room is always 20°F. higher than the outside air, and this is done by adequate heating. The other way is to make the air in the storage space dry and to keep it dry. Under these conditions heating can be dispensed with.

However, it is true that electrode coatings, even of the low hydrogen type will not take up moisture from the air if the relative degree of humidity is not more than 50% and the humidity can be effectively determined by a relatively low cost hygrometer which will give a reading in a matter of seconds provided it is left in the storage area at all times and the area is above freezing.

Humidity below 50% can be ensured by always keeping the storage room at a temperature 20°F. above that of outside air. Under these conditions even with saturated outside air (100% humidity) that of the storage room will be no greater than 50% and if the outside air is less than 100% the inside air will be less than 50%. For instance, if the outside air is 60% humidity, the inside will be one-half of that, or 30%.

To be sure that the air in the dry room is in sufficient contact with the outside air, it is necessary to have some ventilation in the dry room. The best way is to arrange for the air to enter at ground level and is thus heated at that point immediately upon entering the store. Warm air will rise, so the air outlet should be placed as high as possible.

The actual heating can be done in various ways, steam or electrical heating being most commonly used. It is essential, however, that the room be continuously and uniformly heated, and for this reason the electrical method may be rather expensive. When steam is used, any small leaks in the system must be avoided.

Unheated Dry-Storage - In a dry room where no heating is applied, care should be taken to ensure that the air never has a relative degree of humidity higher than 50%. This can be achieved by placing very hygroscopic matter in the room to take up the moisture. It will be clear that, in such a dry room, all ventilation should be avoided, as air entering from outside always brings in more moisture. Such a dry store room should be without windows and should have an airtight door, which must, of course, be used as little as possible, because every time the door is opened a great deal of the dry air will be replaced by more humid air from outside.

As hygroscopic matter, several products can be used, one of the cheapest being calcium chloride. It becomes fluid by absorbing moisture, so that one can see whether the calcium chloride is in good condition or whether it has to be replaced. The price of calcium chloride is so low that, although it is possible to regenerate it, this is not usually done.

A much more expensive produce is silica-gel. In a dry state it is blue-violet, but in taking up water the color changes gradually to pink. The advantage of this product is that it is very easy to regenerate it. Regeneration is done by placing the silica-gel on a hot plate, and the color changes again from pink to blue-violet, so that the silica-gel can be used for a long time. The higher price asked for this material is, therefore, perhaps justifiable. The actual dimensions of the dry room depend on the quantity of electrodes to be stored.

A useful type of storage bin, which has been specially designed for the storage of low hydrogen electrodes for the smaller consumers and for use on site work, is shown in Figure 5.10. To make handling as simple as possible, the hot plate for the regeneration of the moist silica-gel has been placed within the bin. As soon as the color of the silica-gel becomes pink, which can be most conveniently observed by the silica-gel in the glass tube placed on the side of the body of the bin, the lid is taken off and the rubber plug at the bottom is removed. By connecting the electrical plug to the mains the silica-gel will be dried out, and its original blue-violet color will once more re-appear. When this occurs, it will resume its original function; the electrical plug is then disconnected, and the bin is closed again by replacing the rubber plug, and putting on the lid. It must not be forgotten that the lid should be taken off before regeneration, and it must not be replaced before the whole process has been completed, so as to enable the air to circulate. If this is not done, the moisture gathered in the silica-gel will be taken up by the electrodes.

A dry storage bin, of the type shown in Figure 5.10 can be made at a small cost. The hot plate should be rated at 500 watts, and a quantity of 10 lbs. of silica-gel will be sufficient for a long period of time. As has already been noted, it is possible to use calcium chloride instead of silica-gel as the hygroscopic medium. It will then be necessary, however, to make a kind of 'ash tray' in the lower part of the cylindrical wall of the bin, and in order to avoid the entry of humid air it is necessary that this tray should fit very accurately in the wall of the bin. Two types of Dry Rod Ovens are shown in Figures 5.11 and 5.12.

From what has already been said about the detrimental effect of moisture in electrode coatings, the importance of proper packing will be

obvious and particularly for low hydrogen electrodes since these are used for the express purpose of reducing the inherent dangers of moisture.

Assuming that the electrodes have been properly packaged and stored, the problem only arises if the package is punctured or opened and the electrode exposed to the outside air for a few days. Under these conditions, low hydrogen electrodes as well as others will have a tendency to pick up moisture. This may not only cause cracks but also (1) internal porosity in overhead multiple pass welds if the moisture pick up is small; (2) internal porosity in any position if the moisture pick up is moderate but somewhat greater than in (1) above, and (3) surface holes in any position if the moisture pick up is high.

Proper redrying eliminates the moisture and restores the electrode's ability to deposit sound welds. It is recommended however that a minimum stock of electrodes (of any kind) be kept open and subect to normal air, or even in heated storage, in order to preclude the possibility of deterioration.

Electrodes which have been exposed to excessive moisture should be returned to the manufacturer for reconditioning - or perhaps better scrapped. In all cases of drying the maker's recommendations should be followed.

For electrodes other than the low hydrogen type, most manufacturers will recommend a baking at 350 to 400° F. for a few hours and any temperature above boiling, i.e. 212°F. is helpful but the time required to drive off the moisture is longer.

Recommendations for reconditioning low hydrogen electrodes are subject to more variations and manufacturers' recommendations should be sought and followed.

It is generally agreed that electrodes which have come into contact with water or been exposed to normal air for a week or more should be dried at 700°F. for a minimum of one hour. This is close to the original temperature of manufacture and usually means returning to the maker.

Electrodes which have been exposed to normal air for less than a week but have not come into actual contact with water, may be dried for an hour at 500° F. A longer time at a lower temperature is not equivalent and drying at any lower temperature does not fully restore quality and therefore should not be considered.

Repeated reheating at high temperatures may damage the coating and is therefore inadvisable.

BIBLIOGRAPHY

CSA STANDARDS

W48.1 - Specification for Mild Steel Arc-Welding Electrodes

W48.2 - Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes

AWS STANDARDS

A5.1-58 - Specifications for Mild Steel Arc-Welding Electrodes

A5.3-43 - Specifications for Aluminum and Aluminum-Alloy Metal Arc-Welding Electrodes

A5.4-55 - Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes

A5.5-58 - Specifications for High Tensile and Low-Alloy Steel Covered Arc-Welding Electrodes

A5.6-57 - Specifications for Copper and Copper-Alloy Welding Electrodes

A5.9-53 - Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Rods and Bare Electrodes

A5.10-57 - Specifications for Aluminum and Aluminum-Alloy Welding Rods and Bare Electrodes

A5.11-54 - Specifications for Nickel and Nickel-Base Alloy Covered Welding Electrodes

A5.12-55 - Specifications for Tungsten Arc-Welding Electrodes

A5.13-56 - Specification for Surfacing Welding Rods and Electrodes

A5.14-56 - Specification for Nickel and Nickel-Base Alloy Bare Welding Filler Metals

A5.15-56 - Specification for Welding Rods and Covered Electrodes for Welding Cast Iron

A5.0-57 - Filler Metal Comparison Charts

LITERATURE

1. Study of Core Wire for Electrodes, by C. B. Voldrich and others, Welding Journal, June 1950, pp. 265-284 s.
2. Filler Metals for Joining, by O. T. Barnett, Welding Engineer, December, 1956, pp. 54-60.
3. Iron-Powder Electrodes and Their Application, by J. Hinkel, the Welding Journal, September 1954.

(Continued)

4. Metal-Powder Electrodes and Their Application, by E. Di Liberti, The Welding Journal, August 1956, pp. 791-795.

5. Recent Developments on Contact Electrodes, by D. L. Mathias, The Welding Journal, April 1955, pp. 316-328.

6. The Facts About Low Hydrogen Electrodes, by R. K. Lee and others, "Canadian Welder", July 1955.

7. Basic Coated Electrodes and Their Characteristics, by H. F. Tremlett, Welding and Metal Fabrication, July 1951, p. 259.

8. Trends in Arc Welding Electrodes for the Welding of Medium and High Tensile Steels, by J.F. Mercer, Welding and Metal Fabrication, September 1953, p. 324.

9. Transformation Temperature of Alloy Steels Related to Weldability with Low Hydrogen Electrodes, by C.L.M. Cotrell, British Welding Journal, September 1954, p. 409.

10. Low Hydrogen Welding Rods, by J. D. Fast, Welding Journal, June 1953, p. 516.

11. The Welding of Type 347 Steels, by A. Hoerl and others, The Welding Journal, October 1957, p. 442 s.

12. Welding Austenitic Stainless Steels for Gas-Turbine Rotors, by R.R. Roberts British Commonwealth Welding Conference, London, 1957, p. 315.

13. How to Weld Stainless Steels, by L. F. Spencer, Welding Engineer, October 1952.

14. Welding and Its Effects on the Corrosion Resistance of Stainless Steel, by E. W. Hopper, The Welding Journal, June 1951, p. 503.

15. Low Hydrogen Electrodes and Electrode Storage, The Welding Digest, Canadian Welding Bureau, December 1956, pp. 10-21 s.

16. Metal-Powder Electrodes and Their Application, The Welding Digest, Canadian Welding Bureau, May 1957, pp. 19-24 s (Reprint of Ref. 4).

Books and Pamphlets on Stainless Steel Welding

17. The Welding of austenitic corrosion- and heat-resisting steels, British Welding Research Association, London, 1953.

18. Stainless Steels, by Carl A. Zapffe, New York, 1954.

19. Seven Common Troubles found in Welding Stainless and Other Alloy Steels by J. Norcross, Arcos Corporation, Philadelphia, 1950.

20. AWS Welding Handbook, Third Edition, pp. 620-671.

21. The Welding Encyclopedia, Thirteenth Edition, pp. 668-674.

Classification	Current and Polarity	Welding Positions	Type of Covering	Penetration	Surface Appearance	Slag
EXX10	DC, reverse polarity (electrode positive)	All	High-cellulose sodium	Deep	Flat, wavy	Thin
EXX11	AC or DC, reverse polarity	All	High-cellulose potassium	Deep	Flat, wavy	Thin
E6012	DC, straight polarity (electrode negative)	All	High-titania sodium	Medium	Convex, rippled	Heavy
EXX13	AC or DC, straight polarity	All	High-titania sodium	Shallow	Flat or concave, slight ripple	Medium
EXX14	DC, either polarity or AC	All	Iron powder-titania	Medium	Flat, slightly convex, smooth ripple	Easily removed
EXX15	DC, reverse polarity	All	Low hydrogen sodium	Medium	Flat, wavy	Medium
EXX16	AC or DC, reverse polarity	All	Low hydrogen potassium	Medium	Flat, wavy	Medium
EXX18	AC or DC, reverse polarity	All	Iron powder low hydrogen	Shallow	Flat, smooth, fine ripple	Medium
EXX20	DC, straight polarity or AC for H-fillets; DC, either polarity or AC for flat welds	H-fillets and flat	High iron oxide	Medium	Flat or concave, smooth	Heavy
EXX24	DC, either polarity or AC	H-fillets and flat	Iron powder titania	Shallow	Slightly convex, very smooth, fine ripple	Heavy
EXX27	DC, straight polarity or AC for H-fillets; DC either polarity or AC for flat welds	H-fillets and flat	Iron powder iron oxide	Medium	Flat to slightly concave, smooth, fine ripple	Heavy
EXX28	AC or DC, reverse polarity	H-fillets and flat	Iron powder low hydrogen	Shallow	Flat, smooth, fine ripple	Medium
EXX30	DC, either polarity or AC	Flat only	High iron oxide	Shallow	Flat, smooth	Heavy

Table 5.1

Operating Characteristics of Mild Steel and Low-Alloy Steel Electrodes

Group Color — No Color													
Spot Color \ End Color	No Color	Blue	Black	White	Gray	Brown	Violet	Green	Red	Yellow	Orange	Bronze	Silver
No Color	E6010	E7010G		E8010G		E9010G		E10010G			EST*		Mil G6010
White	E6012	E7010–A1									ECI*		
Brown	E6013		E7014	E8010–B1					E6014				
Green	E6020			E8010–B2									
Red	E6015												
Bronze													
Blue	E6011	E7011G		E8011G		E9011G		E10011G					Mil G6011
Yellow	E6024	E7011–A1	E7024										
Black			E7028	E8011–B1		E8011–B2			E6028				
Orange	E6016								E6018				
Violet	E6030												
Gray													
Silver	E6027												

* These letters refer to electrodes in the AWS-ASTM Tentative Specifications for Welding Rods and Covered Electrodes for Welding Cast Iron, AWS A 5.15, ASTM A 398.

NOTE I—AWS classification numbers refer to electrodes in the following AWS-ASTM Tentative Specifications:
Mild Steel Arc-Welding Electrodes, AWS A 5.1, ASTM A 233.
High Tensile and Low-Alloy Steel Covered Arc-Welding Electrodes, AWS A 5.5, ASTM A 316.

NOTE II—When an electrode is simultaneously classified as E70XX and E60XX in AWS Specification A 5.1, ASTM A 233, the color identification shall be in accordance with the E70XX classification.

Table 5.2
Color Identification for Covered Mild-Steel and Low-Alloy Steel Electrodes
XX10, XX11, XX14, XX24, XX27, XX28 and All 60XX

Group Color — Silver													
Spot Color \ End Color	No Color	Blue	Black	White	Gray	Brown	Violet	Green	Red	Yellow	Orange	Bronze	Silver
Brown				E8013G		E9013G		E10013G					
White				E8013–B1		E8013–B2							
No Color													
Black													
Red													
Blue													
Bronze													
Green		E7020G											
Yellow		E7020–A1											
Orange													
Violet													
Gray													
Silver													

NOTE I—AWS classification numbers refer to electrodes in AWS-ASTM Tentative Specifications for High Tensile and Low-Alloy Steel Covered Arc-Welding Electrodes, AWS A 5.5, ASTM A 316.

NOTE II—When an electrode is simultaneously classified as E70XX and E60XX in AWS Specification A 5.1, ASTM A 233, the color identification shall be in accordance with the E70XX classification.

Table 5.3
Color Identification for Covered Low-Alloy Steel Electrodes
All XX13 and XX20 Except E6013 and E6020

Spot Color \ End Color	Group Color — Green											
	No Color	Blue	Black	White	Gray	Brown	Violet	Green	Red	Yellow	Orange	Bronze	Silver
No Color									Mil 11018				
Red	E7015G	E7015		E8015–C3	E8015G	E9015G		E10015G	E11015G	Mil 260–15	E12015G		Mil 230–15
White		E7015–A1	E9015–B3L	E8015–C2	Mil 94LC–16	E9015–D1			Mil 11015	Mil 12015			
Brown				E8015–B1									
Green			E8015–B2L	E8015–B2	Mil 52LC–16	E9015–B3							
Bronze			E8015–B4L	E8015–C1	Mil 82LC–16	E8015–B4							
Orange	E7016G	E7016	E7018	E8016–C3		E9016G		E10016G	Mil 9018	Mil 260–16	E12016G		Mil 230–16
Yellow		E7016–A1	E7018–A1	E8016G		E9016–D1		E10015–D2	E11016G	Mil 12016			
Black			E8018–C3	E8016–B1	E8018–B1		E9018–B3						
Blue	E7018G		8018G	E8016–C1	E8018–C1	E9016–B3	E9018G	E10018G	E11018G		E12018G		
Violet			Mil 10018	E8016–C2	E8018–C2	E8016–B4	E9018–D1	E10018–D2					
Gray			E8018–B4	E8016–B2	E8018–B2			E10016–D2					
Silver			Mil 12018										

NOTE I—AWS classification numbers refer to electrodes in the AWS-ASTM Tentative Specifications for High Tensile and Low-Alloy Steel Arc-Welding Electrodes, AWS A 5.5, ASTM A 316.
NOTE II—Mil type numbers refer to electrodes in military specifications.
NOTE III—When an electrode is simultaneously classified as E70XX and E60XX in AWS Specification A 5.1, ASTM A 233, the color identification shall be in accordance with the E70XX classification.

Table 5.4
Color Identification for Covered Low-Hydrogen Low-Alloy Steel Electrodes
XX15, XX16 and XX18 Except E6015, E6016 and E6018

Spot Color \ End Color	Group Color — Black											
	No Color	Blue	White	Brown	Green	Red	Yellow	Black	Orange	Violet	Gray	Bronze	Silver
No Color	Mil 308 MoL–15 Mil 308 MoT–15			E308LC–15	E330–15	E310–15	E308–15	E309–15					
Blue				Mil 202 LC–15		E310Cb–15	E347–15	E309Cb–15			E502–15		
White				E316LC–15		E310Mo–15	E316–15	E309Mo–15			9Cr–1Mo (Type 505)		
Brown						20–29+ Cu+Mo	E317–15				E410–15		
Green							E318–15				E430–15		
Red					E312–15		Mil 308 HC–15				18Cr (Type 442)		
Yellow		Mil 16.8.2–15					Mil 347 HC–15				28Cr (Type 446)		
Black	Mil 307 L–15 Mil 307 T–15				15–35HiC (Type 330HiC)								
Orange							19–9WMo (Type 349)						
Violet													
Gray													
Bronze													
Silver													

NOTE I—Type numbers are those of the American Iron and Steel Institute. The weld analysis nearest to that specified by AISI is the one used here for reference.
NOTE II—AWS classification numbers refer to electrodes in the AWS-ASTM Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes, AWS A 5.4, ASTM A 298.
NOTE III—Mil type numbers refer to electrodes in military specifications.

Table 5.5
Color Identification for Covered Chromium and Chromium-Nickel Steel Electrodes
Direct Current

Group Color — Yellow													
Spot Color \ End Color	No Color	Blue	White	Brown	Green	Red	Yellow	Black	Orange	Violet	Gray	Bronze	Silver
No Color	Mil 308 MoL–16 Mil 308 MoT–16			E308LC–16	E330–16	E310–16	E308–16	E309–16					
Blue				Mil 202 LC–16		E310Cb–16	E347–16	E309Cb–16			E502–16		
White				E316LC–16		E310Mo–16	E316–16	E309Mo–16			9Cr–1Mo (Type 505)		
Brown						20–29+ Cu+Mo	E317–16				E410–16		
Green							E318–16				E430–16		
Red					E312–16		Mil 308 HC–16				18Cr (Type 442)		
Yellow		Mil 16.8.2–16					Mil 347 HC–16				28Cr (Type 446)		
Black	Mil 307 L–16 Mil 307 T–16				15–35HiC (Type 330HiC)								
Orange							19–9WMo (Type 349)						
Violet													
Gray													
Bronze													
Silver													

NOTE I—Type numbers are those of the American Iron and Steel Institute. The weld analysis nearest to that specified by AISI is the one used here for reference.

NOTE II—AWS classification numbers refer to electrodes in the AWS-ASTM Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes, AWS A 5.4, ASTM A 298.

NOTE III—Mil type numbers refer to electrodes in military specifications.

Table 5.6
Color Identification for Covered Chromium and Chromium-Nickel Steel Electrodes
Alternating and Direct Current

Group Color — Blue													
Spot Color \ End Color	No Color	Blue	White	Brown	Green	Red	Yellow	Black	Orange	Violet	Silver	Bronze	Gray
No Color					ECu	ECu–Si	ECu–SnA						
Blue	ECu–Ni						ECu–SnC				ECu–Al–A2		
White													
Brown											ECu–Al–B		
Green											ECu–Al–C		
Red											ECu–Al–D		
Yellow											ECu–Al–E		
Black													
Orange													
Violet													
Gray													
Bronze													
Silver													

NOTE—AWS classification numbers refer to electrodes in the following AWS-ASTM Tentative Specifications:
Copper and Copper-Alloy Welding Electrodes, AWS A 5.6, ASTM B 225.
Surfacing Welding Rods and Electrodes, AWS A 5.13, ASTM A 399.

Table 5.7
Color Identification for Covered Copper and Copper-Alloy Electrodes

Group Color — White													
Spot Color \ End Color	No Color	Blue	White	Brown	Green	Red	Yellow	Black	Orange	Violet	Silver	Bronze	Gray
No Color													
Blue					Ni–Cr 60–13				ENi*				
White		E3N10			Ni–Cr 85–15		E3N11		ENiCu*	E3N12		Mil 3N1L	
Brown		E4N10			E4N12		E4N11		ENiFe*				
Green			E3N1B						ENiCuB*				
Red		E3N14								E3N19			
Yellow			Mil 4N1W										
Black													
Orange												Mil 3N1N	
Violet			E3N1C										
Gray													
Bronze													
Silver													

* These letters refer to electrodes in the AWS-ASTM Tentative Specifications for Welding Rods and Covered Electrodes for Welding Cast Iron, A 5.15, ASTM A 398.
NOTE I—AWS classification numbers refer to electrodes in the AWS-ASTM Tentative Specifications for Nickel and Nickel-Base Alloy Covered Welding Electrodes, AWS A 5.11, ASTM B 295.
NOTE II—Mil type numbers refer to electrodes in military specifications.

Table 5.8
Color Identification for Covered Nickel, Nickel-Alloy and High-Temperature-Alloy Electrodes

Group Color — Red													
Spot Color \ End Color	No Color	Blue	White	Brown	Green	Red	Yellow	Black	Orange	Violet	Silver	Bronze	Gray
No Color		EFeMn–A	EFeCr–A1	EFe5–A		ENiCr–A							
Blue		EFeMn–B	EFeCr–A2	EFe5–B		ENiCr–B							
White				EFe5–C		ENiCr–C							
Brown													
Red					ECoCr–A								
Green					ECoCr–B								
Yellow													
Black					ECoCr–C								
Orange													
Violet													
Gray													
Bronze													
Silver													

NOTE—AWS classification numbers refer to electrodes in the AWS-ASTM Tentative Specifications for Surfacing Welding Rods and Electrodes, AWS A 5.13, ASTM A 399.

Table 5.9
Color Identification for Covered Surfacing Electrodes

AWS-ASTM Classification	Tensile Strength, 1000 psi,	Yield Strength, 1000 psi,	Elongation in 2 in., per cent	Reduction of Area, per cent	Charpy Keyhole, ft-lb		Charpy V-Notch, ft-lb	
					70 F	−40 F	70 F	−40 F
E6010	60 to 68	48 to 58	22 to 28	35 to 60	30 to 40	15 to 25	50 to 80	10 to 25
E6011	60 to 70	48 to 61	22 to 30	35 to 60	30 to 40	15 to 25	50 to 80	10 to 25
E6012	60 to 78	48 to 65	17 to 22	20 to 40	20 to 30	5 to 15	25 to 55	2 to 10
E6013	60 to 78	48 to 65	17 to 22	25 to 50	25 to 35	5 to 20	30 to 60	5 to 15
E6020 and E6030	60 to 68	48 to 58	25 to 30	40 to 60	25 to 35	15 to 25	40 to 70	10 to 25
E6027	~~60~~ 62 to ~~68~~ 72	~~48~~ 50 to ~~55~~ 64	25 to 30	40 to 60	25 to 35	15 to 25	40 to 70	10 to 25
E6014	60 to 72	48 to 60	17 to 25	30 to 50	25 to 35	15 to 25	40 to 70	10 to 25
E7014	70 to 85	58 to 77						
E6015 and E6016	60 to 72	48 to 60	22 to 35	55 to 75	35 to 50	25 to 40	70 to 100	25 to 40
E7015 and E7016	70 to 76	58 to 62						
E6018	60 to 72	48 to 60	22 to 30	55 to 75	35 to 50	25 to 40	70 to 100	25 to 40
E7018	70 to 85	58 to 70						
E6024	60 to 72	48 to 60	17 to 22	20 to 40	25 to 35	10 to 20	30 to 60	5 to 20
E7024	70 to 85	58 to 75						
E6028	60 to 72	48 to 60	22 to 30	55 to 75	35 to 50	25 to 40	70 to 100	15 to 40
E7028	70 to 85	58 to 74						

Table 5.10
Mechanical Properties
(these properties are to be expected in the as-welded condition)

Electrode Diameter, in.	E 6010 and E 6011	E 6012	E 6013	E 6020 and E 6030	E 6027	E 6014 and E 7014	E 6015, E 6016, E 7015, and E 7016	E 6018 and E 7018	E 6024, E 6028, E 7024, and E 7028
1/16	...	20 to 40	20 to 40	...	...	...	...	...	...
5/64	...	25 to 60	25 to 60	...	...	...	...	...	...
3/32	40 to 80	35 to 85	45 to 90	...	...	80 to 125	65 to 110	70 to 100	100 to 145[a]
1/8	75 to 125	80 to 140	80 to 130	100 to 150	125 to 185	110 to 160	100 to 150	115 to 165	140 to 190
5/32	110 to 170	110 to 190	105 to 180	130 to 190	160 to 240	150 to 210	140 to 200	150 to 220	180 to 250
3/16	140 to 215	140 to 240	150 to 230	175 to 250	210 to 300	200 to 275	180 to 255	200 to 275	230 to 305
7/32	170 to 250	200 to 320	210 to 300	225 to 310	250 to 350	260 to 340	240 to 320	260 to 340	275 to 365
1/4	210 to 320	250 to 400	250 to 350	275 to 375	300 to 420	330 to 415	300 to 390	315 to 400	335 to 430
5/16	275 to 425	300 to 500	320 to 430	340 to 450	450 to 650	390 to 500	375 to 475	375 to 470	...

[a] These values do not apply to the E6028 and E7028 classifications.

Table 5.11
Typical Current Ranges in Amperes for Electrodes

AWS-ASTM Classification	Carbon, per cent	Molybdenum, per cent	Chromium, per cent	Manganese, per cent	Silicon, per cent	Sulfur, per cent	Nickel, per cent	Vanadium, per cent
Carbon-Molybdenum Steel Electrodes								
E7010-A1				0.60	0.40			
E7011-A1				0.60	0.40			
E7015-A1	0.12	0.40 to 0.65	...	0.90	0.60	0.04	...	...
E7016-A1				0.90	0.60			
E7018-A1				0.90	0.80			
E7020-A1				0.60	0.40			
Chromium-Molybdenum Steel Electrodes								
E8010-B1				0.60	0.40			
E8011-B1				0.60	0.40			
E8013-B1	0.12	0.40 to 0.65	0.40 to 0.65	0.60	0.40	0.04	...	...
E8015-B1				0.90	0.60			
E8016-B1				0.90	0.60			
E8018-B1				0.90	0.80			
E8015-B2L	0.05	0.40 to 0.65	1.00 to 1.50	0.90	1.00	0.04	...	...
E8010-B2				0.60	0.40			
E8011-B2				0.60	0.40			
E8013-B2	0.12	0.40 to 0.65	1.00 to 1.50	0.60	0.40	0.04	...	...
E8015-B2				0.90	0.60			
E8016-B2				0.90	0.60			
E8018-B2				0.90	0.80			
E9015-B3L	0.05	0.90 to 1.20	2.00 to 2.50	0.90	1.00			
E9015-B3					0.60			
E9016-B3	0.12	0.90 to 1.20	2.00 to 2.50	0.90	0.60	0.04	...	...
E9018-B3					0.80			
E8015-B4L	0.05	0.40 to 0.65	1.75 to 2.25	0.90	1.00			
E8015-B4					0.60			
E8016-B4	0.12	0.40 to 0.65	1.75 to 2.25	0.90	0.60	0.04	...	...
E8018-B4					0.80			
Nickel Steel Electrodes								
E8015-C1					0.60			
E8016-C1	0.12	...	...	1.00	0.60	0.04	2.00 to 2.75	...
E8018-C1					0.80			
E8015-C2					0.60			
E8016-C2	0.12	...	...	1.00	0.60	0.04	3.00 to 3.75	...
E8018-C2					0.80			
E8015-C3					0.60			
E8016-C3	0.12	...	...	1.00	0.60	0.04	0.80 to 1.10	...
E8018-C3					0.80			
Manganese-Molybdenum Steel Electrodes								
E9015-D1					0.60			
E9016-D1	0.12	0.25 to 0.45	...	1.25 to 1.75	0.60	0.04	...	...
E9018-D1					0.80			
E10015-D2					0.60			
E10016-D2	0.15	0.25 to 0.45	...	1.65 to 2.00	0.60	0.04	...	...
E10018-D2					0.80			
All Other Low Alloy Electrodes								
EXX10-G								
EXX11-G								
EXX13-G								
EXX15-G	...	0.20 min[a]	0.30 min[a]	1.00 min[a]	0.80 min[a]	...	0.50 min[a]	0.10 min[a]
EXX16-G								
EXX18-G								
E7020-G								

[a] In order to meet the alloy requirements of the G group, the deposit need have the minimum, as specified in the table, of only one of the elements listed.

Table 5.12
Chemical Requirements
for low alloy steel arc welding electrodes

Note: Single values shown are maximum percentage, except where otherwise specified.

E60 SERIES ELECTRODES *

Increased values of improvements in direction of arrow →

		Conventional mild steel electrodes	Straight Iron Powder types	Low Hydrogen iron powder types
Operating Characteristics	Penetration	6013 6012 6016 6020 6011 6010	6024 6014 6027	6028 6018
	Arc Force	6012 6013 6016 6020 6011 6010	6024 6014 6027	6028 6018
	Undercutting	6010 6011 6020 6016 6012 6013	6027 6014 6024	6018 6028
	Ease of Handling	6010 6011 6016 6020 6012 6013	6027 6014 6024	6018 6028
	Ease of Restriking	6020 6016 6011 6010 6012 6013	6027 6014 6024	6018 6028
	Poor Fit Up	6020 6016 6010 6011 6013 6012	6027 6024 6014	6028 6018
	Light Gauge Plate	6010 6011 6016 6013 6012	6024 6014	6018
	Overhead Usability	6012 6016 6013 6011 6010	6014	6018
	Vertical Up	6012 6016 6013 6011 6010	6014	6018
	Vertical Down	6016 6011 6012 6013 6010	6014	6018
Weldability	Tensile	6020 6010 6011 6013 6012 6016	6027 6014 6024	6018 6028
	Ductility	6012 6013 6010 6011 6020 6016	6014 6024 6027	6028 6018
	Impact Value	6012 6013 6011 6010 6020 6016	6024 6014 6027	6028 6018
	Sensitivity **	6020 6011 6010 6013 6012 6016	6014 6024 6027	6028 6018
	Bead Appearance	6010 6011 6016 6012 6013 6020	6014 6024 6027	6018 6028
	Soundness	6012 6013 6010 6011 6016 6020	6014 6024 6027	6018 6028
Cost Factors	Slag Removal	6010 6016 6011 6012 6013 6020	6014 6024 6027	6018 6028
	Spatter Loss	6010 6011 6016 6012 6013 6020	6014 6024 6027	6028 6018
	Current Capacity	6010 6011 6013 6012 6016 6020	6014 6024 6027	6018 6028
	Steel to Flux Ratio	6020 6016 6013 6012 6011 6010	6024 6014 6027	6028 6018
	Deposition Efficiency	6020 6011 6010 6016 6013 6012	6024 6027 6014	6028 6018
	Deposition Rate	6011 6010 6012 6013 6016 6020	6014 6024 6027	6018 6028

* Values will have the same relationship for other series.

** To plate composition in the order of improvement.

Note: An E6015 is made by some manufacturers specifically for DC. All its characteristics are identical with E6016.

Table 5.13
Comparative Electrode Characteristics:-
Applicable to E60, 70, 80, 90, 100, 110 and 120 series

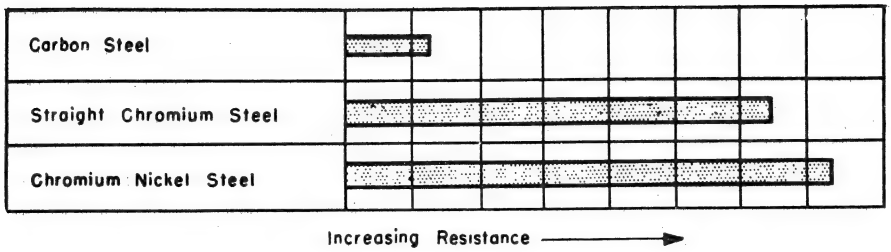


Fig. 5.1
Electric Resistance of Steels

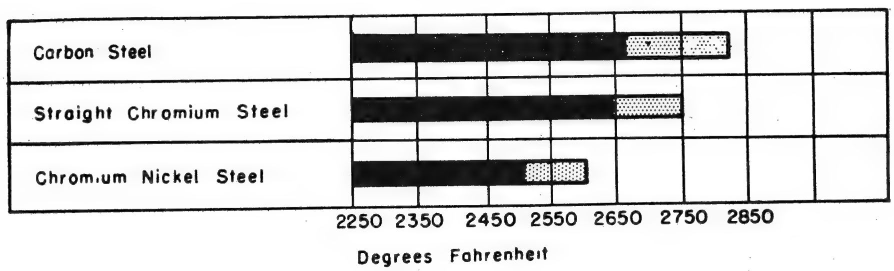


Fig. 5.2
Melting Point of Steels

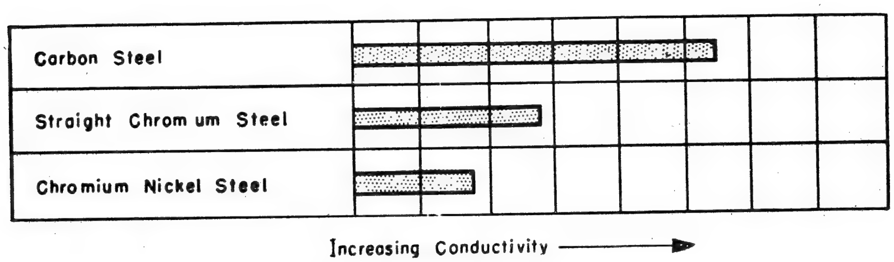


Fig. 5.3
Thermal Conductivity of Steels

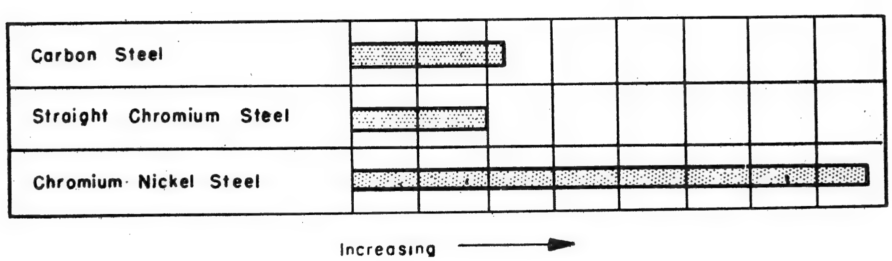


Fig. 5.4
Coefficient of Linear Expansion of Steels

Fig. 5.5

Right: Unstabilized Type 302 steel plate welded with unstabilized electrode. Accelerated corrosion test revealed heavy carbide precipitation.

Left: ELC Type 316 steel plate welded with unstabilized wire (Mig Process) and quenched in water immediately after welding - no traces of carbide precipitation.

	Metallurgical Structure		
Characteristics	Martensitic 4% to 14% Chromium	Martensitic-Ferritic 14% to 18% Chromium	Ferritic 18% to 30% Chromium
Corrosion Resistance	Not susceptible to loss of corrosion resistance through intergranular carbide precipitation.		
Hardening Characteristics	Hardens in weld zone when cooled in air after welding.	Characteristics of this class fall on or between those listed for the other two classes, depending on the comparative amounts of carbon and chromium present.	Does not harden even when cooled rapidly.
Ductility of Metal	Reduced by welding. Improved by heat treatment.		Reduced by welding. Improved some by annealing, depending on chromium content.
Response to Heat Treatment	Wide range of mechanical properties obtainable under heat treatment.		No range of properties obtainable by heat treatment.
Effects of Welding on Grain of Metal	Subject to grain growth, causing brittleness. *Can* be restored by heat treatment.	Subject to grain growth, causing brittleness. *May* be restored, *may partially* be restored or *may not* be restored according to metallurgical structure.	Subject to grain growth, causing brittleness. *Cannot* be restored. Must be minimized by low heat input. Employ fast cooling rate from 1200 F to below 800 F.
Coefficient of Expansion	Same or slightly less than that of plain carbon steel.		
Heat Conductivity	Varies from 70 to 40% of common steel, depending on chromium content.		
Electrical Resistance	Varies from three to six times that of plain carbon steel, depending upon chromium content.		
Melting Point	Slightly less than that of plain carbon steel.		
Welding	Use preheat and post-heat treatments when welding.		

Table 5.14

Effect of Welding Heat on Straight-Chromium Stainless Steels

AISI designation	Popular designation*	Chemical Composition,† % C	Cr	Ni	Other elements	Welding recommendations recommended electrode‡
301	17–7	0.08–0.20	16.0–18.0	6.0–8.0	....	E308
302	18–8	0.08–0.20	17.0–19.0	8.0–10.0		E308
302 B	18–8 Si	0.08–0.20	17.0–19.0	8.0–10.0	Si 2.0–3.0	E308
303	18–8 FM	0.15 max	17.0–19.0	8.0–10.0	P, S, Se 0.07 min, Zr, Mo 0.60 max	E308§
304	19–9	0.08 max	18.0–20.0	8.0–11.0		E308
304 L	19–9 (extra-low carbon)	0.03 max	18.0–20.0	8.0–11.0		308L or E347
305	18–10	0.12 max	17.0–19.0	10.0–13.0		E308
308	20–10	0.08 max	19.0–21.0	10.0–12.0		E308
309	24–12	0.20 max	22.0–24.0	12.0–15.0		E309
309 S	24–12 (low carbon)	0.08 max	22.0–24.0	12.0–15.0		E309
309 Cb	24–12 Cb	0.20 max	22.0–24.0	12.0–15.0	Cb 10 × C min	309 Cb
310	25–20	0.25 max	24.0–26.0	19.0–22.0		E310
310 S	25–20 (low carbon)	0.08 max	24.0–26.0	19.0–22.0		E310
310 Cb	25–20 Cb	0.25 max	24.0–26.0	19.0–22.0	Cb 10 × C min	310 Cb
310 Mo	25–20 Mo	0.25 max	24.0–26.0	19.0–22.0	Mo 2.0–3.0	310 Mo
314	25–20 Si	0.25 max	23.0–26.0	19.0–22.0	Si 1.5–3.0	
316	18–12 Mo	0.10 max	16.0–18.0	10.0–14.0	Mo 2.0–3.0	E316
316 L	18–12 Mo (extra-low carbon)	0.03 max	16.0–18.0	10.0–14.0	Mo 2.0–3.0	316L or 318
317	19–13 Mo	0.10 max	18.0–20.0	11.0–14.0	Mo 3.0–4.0	E317
318‖	18–12 Mo Cb	0.10 max	18.0–20.0	10.0–14.0	Mo 2.0–3.0, Cb 10 × C min	318
321	18–8 Ti	0.08 max	17.0–19.0	8.0–11.0	Ti 5 × C min	E347
347	18–8 Cb	0.08 max	17.0–19.0	9.0–12.0	Cb 10 × C min	E347

* The 17–7, 18–10, 19–9, 19–12 designation are also often described as 18–8.
† Unless otherwise specified Mn is 2.00% max., Si is 1.00% max., P is 0.040% max. and S is 0.030% max.
‡ Characteristics of the commercial stainless steel welding electrodes are given in Table 5
§ Lime-type coatings preferred.
‖ Presently not recognized by AISI.

Table 5.15

Composition and welding recommendations for common commercial austenitic stainless steel grades recognized by the American Iron and Steel Institute (AISI)

ACI designation	Popular designation	Chemical composition,* % C	Cr	Ni	Other elements, %	Welding recommendations, recommended electrode†
CE-30	25–10	0.30 max	26–30	8–11	.....	312
CF-8	19–9	0.08 max	18–21	8–11	.....	E308
CF-20	19–9	0.20 max	18–21	8–11	.....	E308
CF-8M	19–10 Mo	0.08 max	18–21	9–12	Mo 2.0–3.0, Si 1.50 max	E316
CF-12M	19–10 Mo	0.12 max	18–21	9–12	Mo 2.0–3.0, Si 1.50 max	E316
CF-8C	19–10 Cb	0.08 max	18–21	9–12	Cb 8 × C min, 1.0 max	E347
CF-16F	19–10 MoFM	0.16 max	18–21	9–12	Mo 1.5 max, Se 0.20–0.35, P 0.17 max	E308‡
CF-16Fa	19–10 MoFM	0.16 max	18–21	9–12	Mo 0.40–0.80, S 0.20–0.40	E308‡
CG-12	22–12	0.12 max	20–23	10–13	.....	E309
CH-10	25–12	0.10 max	22–26	12–15	.....	E309
CH-20	25–12	0.20 max	22–26	12–15	.....	E309
CK-20	25–20	0.20 max	23–27	19–22	.....	E310
CN-7M Cu	...	0.07 max	18–22	21–31	Cu, Mo, Si§	Special electrode [4, 5]
HC	28–4	0.50 max	26–30	4 max	Mn 1.00 max, Mo 0.5 max‖	329
HD	28–7	0.50 max	26–30	4–7	Mo 0.5 max‖	312
HE	28–10	0.20–0.50	26–30	8–11	Mn 2.00 max, Mo 0.5 max‖	312
HF	20–10	0.20–0.40	18–23	8–12	Mn 2.00 max, Mo 0.5 max‖	E308
HG	...	...	...	...	.....	E308
						E309
HH	27–12	0.20–0.50	24–48	11–14	Mn 2.00 max, Mo 0.5 max, N_2 0.2 max‖	E309
HI	28–16	0.20–0.50	26–30	14–18	Mn 2.00 max, Mo 0.5 max‖	E309
HK	25–20	0.20–0.60	24–28	18–22	Mn 2.00 max, Si 3.00 max, Mo 0.50 max‖	E310
HL	30–20	0.20–0.60	28–32	18–22	Mn 2.00 max, Si 3.00 max, Mo 0.50 max‖	E310
HN	22–25	0.20–0.50	19–23	23–27	Mn 2.00 max, Si 2.00 max, Mo 0.50 max‖	E310
HT	15–35	0.35–0.75	13–17	33–37	Mn 2.00 max, Si 2.50 max, Mo 0.50 max‖	E330
HU		0.35–0.75	17–21	37–41	Mn 2.00 max, Si 2.50 max, Mo 0.50 max‖	E330**

* Unless otherwise specified Mn is 1.50% max, Si is 2.00% max, P and S are 0.04% max.
† Characteristics of the commercial stainless steel electrodes are given in Table 5
‡ Electrodes with lime-type coatings preferred.
§ There are several proprietary alloy compositions falling within the stated chromium and nickel ranges, and containing varying amounts of silicon, molybdenum and copper. Such alloys are available from licensed producers only.
‖ Molybdenum not intentionally added.
** 18–38 (Cr-Ni) electrodes also used.

Table 5.16

Composition and welding recommendations for common commercial austenitic casting grades recommended by Alloy Casting Institute (ACI)

	Popular designation	Chemical composition,* %: C	Cr	Other elements	Welding recommendations: Recommended electrode†	Preheat interpass temperature	Postheat treatment at 1300–1450° F (705–790° C) for 1 hr per in. of thickness
AISI designation							
403	12 Cr	0.15 max	11.5–13.0	Turbine quality, Si 0.50 max	E410	600–700° F (315–370° C)	......
410	12 Cr	0.15 max	11.5–13.5	.....	E310 or E309	400–600° F (205–315° C) highly recommended where possible	Recommended‡
					E410	600–700° F (315–370° C)	Highly recommended
410 mod.	12 Cr	0.18 max	11.5–13.5	.....	E310 or E309	300–500° F (150–260° C) highly recommended where possible	Recommended
					E410	300–500° F (150–260° C)	Highly recommended
414	12 Cr–2 Ni	0.15 max	11.5–13.5	Ni 1.25–2.50	E310 or E309	400–600° F (205–315° C)	Highly recommended§
					E410	600–700° F (315–370° C)	Highly recommended
416	12 Cr–FM	0.15 max	12.0–14.0	P, S, Se 0.07 min; Zr, Mo 0.60 max	E430 or E410	600–700° F (315–370° C)	Highly recommended‖
420	13 Cr	Over 0.15	12.0–14.0	.....	E310 or E309	400–600° F (205–315° C)	Recommended
					E410 or E430	600–700° F (315–370° C)	Highly recommended
431	16 Cr–2 Ni	0.20 max	15.0–17.0	.....	E310 or E309	400–600° F (205–315° C)	Recommended
					E430	600–700° F (315–370° C)	Highly recommended
440-A	17 Cr	0.06–0.75	16.0–18.0	Mo 0.75 max	E430 or E442	600–700° F (315–370° C)	Required**
440-B	17 Cr	0.75–0.95	16.0–18.0	Mo 0.75 max			
440-C	17 Cr	0.95–1.20	16.0–18.0	Mo 0.75 max			
ACS designation							
CA-15	12 Cr	0.15 max	11.5–14.0	Mn, Ni 1 max; Si 1.5 max	E310 or E309	400–600° F (205–315° C) highly recommended where possible	Recommended†
					E430	600–700° F (315–370° C)	Highly recommended
CA-40	13 Cr	0.20–0.40	11.5–14.0	Mn, Ni 1 max, Si 1.5 max	E310 or E309	400–600° F (205–315° C)	Recommended
					E410 or E430	600–700° F (315–370° C)	Highly recommended

* Unless otherwise specified Mn and Si are 1.00% max, P is 0.040% max and S is 0.030% max.
† Characteristics of the commercial stainless steel welding electrodes are given in Table 5
‡ When preheat treatments are not employed use small diameter electrodes.
§ On thinner gages, postheat treatments may be omitted.
‖ Welding is not recommended.
** These steels generally are not recommended for welding. When welding or repair welding is necessary pre- and postheat treatments must be employed.

Table 5.17

Composition and welding recommendations for common commercial AISI and ACI martensitic stainless steels

	Popular designation	Chemical composition,* %: C	Cr	Other elements	Welding recommendations: Recommended electrode†	Preheat and interpass temperature	Postheat treatment at 1300–1450° F (705–790° C) 1 hr per in. of thickness
AISI designation							
405	12 Cr–Al	0.08 max	11.5–13.5	Al 0.10–0.30	E430	Not necessary	Highly recommended
					E310 or E309	Not necessary	Recommended
406	12 Cr–4 Al	0.15 max	12.0–14.0	Al 3.50–4.50	E410		‡
430	16 Cr	0.12 max	14.0–18.0		E430	Not necessary	Highly recommended
					E310 or E309	Not necessary	Recommended
430-F	16 Cr–FM	0.12 max	14.0–18.0	P, S, Se 0.07 min; Zr, Mo 0.60 max	E430		Recommended§
442	18 Cr	0.35 max	18.0–23.0		442 or 446	Not necessary, but usually recommended between 300–400° F (150–205° C)	Essential
					E309 or E310		Highly recommended
446	27 Cr	0.35 max	23.0–27.0	N_2 0.25 max	446	300–400° F (150–205° C)	Essential
					E310 or E309	Not necessary	Not necessary‖
ACI designation							
CB-30	20 Cr	0.30 max	18.0–22.0	Ni 2.0 max	E442	Not necessary, but usually recommended between 300–400° F (150–205° C)	Essential
					E309 or E310		Highly recommended
CC-50	27 Cr	0.50 max	26.0–30.0	Ni 4.0 max	E446	300–400° F (150–205° C)	Essential
					E309 or E310	Not necessary	Not necessary
HC	27 Cr	0.50 max	26.0–30.0	Si 2.0 max Ni 4.0 max	E446	300–400° F (150–205° C)	Essential
					E309 or E310	Not necessary	Not necessary

* Unless otherwise specified Mn and Si are 1.00% max, P is 0.040% max and S is 0.030% max.
† Characteristics of the commercial stainless steel welding electrodes are given in Table 5
‡ Not recommended for welding. When repair welding is necessary use Type 310 electrodes of small diameter and low welding currents.
§ Welding is not recommended
‖ For best practice, postheat treatment should be used.

Table 5.18

Composition and welding recommendations for common commercial AISI and ACI ferritic stainless steels

Stainless steel electrodes	Trade designation*	Popular designation†	Chemical composition,‡ %: C	Cr	Ni	Other elements	Electrode current	Electrode covering type	NEMA§ standard electrode color markings: End	Spot	Group	Applications and notes
Austenitic	307	19–9 Mn	0.10 max	19.0 min	9.0 min	Mn 4.00	DC	Lime	None	Black	Black	For hardenable steels, such as armorplate.
	E, ER 308	18–8 or 19–9	0.08 max	19.0 min	9.0 min	.....	DC AC, DC	Lime Titania	Yellow Yellow	None None	Black Yellow	For Types 301, 302, 302B, 303, 304, 305 and 308. Also used to provide a protective overlay on iron alloy or steel surfaces.
	E, ER 308 L	18–8 ELC	0.03 max	18.0–20.5	9.0–10.5	.....	DC AC, DC	Lime Titania	Brown Brown	None None	Black Yellow	For Types 304 L stainless steels.
	E, ER 309	25–12	0.15 max	22.0 min	12.0 min	.....	DC AC, DC	Lime Titania	Black Black	None None	Black Yellow	For Type 309 stainless steels, stainless clad steels and hardenable steels where postheat treatments are not possible.
	309 Cb	25–12 Cb	0.10 max	22.0 min	12.0 min	Cb 10 × C min, 1.20 max	DC AC, DC	Lime Titania	Black Black	Blue Blue	Black Yellow	For Type 309 Cb stainless steels and Type 347 stainless clad steels.
	E, ER 310	25–20	0.20 max	25.0 min	20.0 min	.....	DC AC, DC	Lime Titania	Red Red	None None	Black Yellow	For Type 310 stainless steels, stainless clad steels and hardenable steels where postheat treatments are not possible. To minimize crack sensitivity a minimum carbon content of 0.09% in weld metal is desirable.
	310 Cb	25–20 Cb	0.12 max	25.0 min	20.0 min	Cb 10 × C min, 1.20 max	DC	Lime	Red	Blue	Black	For stabilized Type 310 stainless steels where extreme resistance to carbide precipitation is required and for Type 347 stainless clad steels.
	310 Mo	25–20 Mo	0.15 max	25.0 min	20.0 min	Mo 2.00–2.50	DC	Lime	Red	White	Black	For Type 310 Mo stainless steels and for elevated temperature applications where the added strength provided by Mo is desirable for Type 316 stainless clad steels. To minimize crack sensitivity a minimum carbon content of 0.09% in weld metal is desirable.
	312	29–9	0.08–0.15	26.0–31.0	8.5–10.5	.....	DC	Lime	Green	Red	Black	For hardenable wrought and cast low- and medium-alloy steels requiring weld metal of high yield strength and high ductility.
	E, ER 316	18–12 Mo	0.08 max	17.0 min	11.0 min	Mo 1.75–2.50	DC AC, DC	Lime Titania	Yellow Yellow	White White	Black Yellow	For Type 316 stainless steels.
	E, ER 316 L	18–8 Mo ELC	0.03 max	17.0–19.0	12.0–14.0	Mo 1.75–2.50	DC AC, DC	Lime Titania	Brown Brown	White White	Black Yellow	For Type 316 L stainless steels.
	316 Cb	18–12 Mo Cb	0.08 max	18.0 min	10.0 min	Mo 1.75–2.50; Cb 10 × C min, 1.20 max	DC AC, DC	Lime Titania	Yellow Yellow	Green Green	Black Yellow	For Type 316 Cb stainless steels and high alloy steels used at high temperatures where intergranular carbide precipitation is to be avoided.
	E, ER 317	19–14 Mo	0.03 max	18.0 min	12.0 min	Mo 3.00–4.00	DC AC, DC	Lime Titania	Yellow Yellow	Brown Brown	Black Yellow	For Type 317 stainless steels.
	329	25–3 Mo	0.20 max	23.0–28.0	2.5–5.0	Mo 1.00–2.00	DC	Lime	Green	Yellow	Black	For Type 329 stainless steels.
	E, ER 330	15–35	0.25 max	14.0 min	33.0 min	.....	DC	Lime	Green	None	Black	For Type 330 stainless steels and 15–35 (Cr-Ni) (Type HT) castings where welds require heat resistance up to 1900° F (1040°C). To minimize crack sensitivity a minimum carbon content of 0.18% in weld metal is desirable.
	E, ER 347	19–9 Cb	0.08 max	18.0 min	9.0 min	Cb 10 × C min, 1.20 max; Si 0.08 max	DC AC, DC	Lime Titania	Yellow Yellow	Blue Blue	Black Yellow	For Type 347 and 321 stainless steels and where weldments may be exposed to service temperatures between 800 and 1500° F (425 and 815° C).
	349	19–9 W Mo	0.07–0.13	18.0–21.0	8.0–9.5	W 1.25–1.75; Mo 0.35–0.65; Cb 0.75–1.20	DC	Lime	Yellow	Orange	Black	For high-alloy steels of similar composition exhibiting high creep strength at elevated temperatures.
	Stainless W	...	0.07	17.0	7.0	Cb 2.0	DC	Lime	...	...	...	For stainless W.
	No. 20	20–29 Mo Cu	0.07 max	19.0–21.0	28.0–30.0	Mo 2.0–3.0; Cu 3.5–4.5; Cb 0.75–1.1	DC	Lime	Red	Brown	Black	For 20 Cr, 29 Ni, 3 Mo, 3 Cu stainless steels.
Martensitic	E, ER 410	12 Cr	0.10 max	11.0–13.0	0.50 max	.....	DC	Lime	Gray	Brown	Black	For Types 403, 410 and 414. Preheat and postheat treatments are recommended. (See Table 4.)
	ER 420	12 Cr (C)	0.25–0.40	12.0–14.0	0.60 max	.....	DC	...	...	...	...	For Type 420 martensitic stainless steels.
Ferritic	E, ER 430	16 Cr	0.10 max	15.5–17.0	0.50 max	.....	DC	Lime	Gray	Green	Black	For Types 405, 416, 430, 431 and 440. This grade is less air hardening than Type 410. Ductility is considerably improved by heating to temperatures above 200 to 300° F (95 to 150° C). The alloy is also used for facing valve seats. Preheat and postheat treatments are recommended. (See Table 5.)
	442	18 Cr	0.10 max	17.0–20.0	0.50 max	.....	DC	Lime	Gray	Red	Black	For Type 442 stainless steel. Preheat and postheat treatments are recommended. (See Table 5.)
	446	28 Cr	0.10 max	25.0–29.0	0.50 max	N_2 0.25 max	DC	Lime	Gray	Yellow	Black	For Type 442 and 446 stainless steels. Preheat and postheat treatments are generally recommended. (See Table 5.)

* Prefix E signifies electrodes covered in standard AWS-ASTM designation AWS A5.4–48T, ASTM A298–48T, as being revised by Subcommittee IV of the AWS-ASTM Filler Metal Committee; prefix ER signifies bare electrodes and welding rods covered in standard AWS-ASTM designation AWS A5.9–53T, ASTM A371–53T.
† The 18–12, 19–9, 19–14 grades are written by many manufacturers as 18–8.
‡ Unless otherwise specified Mn is 2.5% max, Si is 0.75% max and P and S are 0.030% max.
§ National Electric Manufacturers' Assn.

Table 5.19

Summary of welding characteristics of commercial stainless steel electrodes and welding rods

	Classification Number	Current[a]	Capable of producing satisfactory welds in positions shown[b]
E308 Series	E308-15	dc	F, V, OH, H
	E308-16	ac and dc	
	E308-25	dc	H-Fillets, F
	E308-26	ac and dc	
E309 Series	E309-15	dc	F, V, OH, H
	E309-16	ac and dc	
	E309-25	dc	H-Fillets, F
	E309-26	ac and dc	
E310 Series	E310-15	dc	F, V, OH, H
	E310-16	ac and dc	
	E310-25	dc	H-Fillets, F
	E310-26	ac and dc	
E316 Series	E316-15	dc	F, V, OH, H
	E316-16	ac and dc	
	E316-25	dc	H-Fillets, F
	E316-26	ac and dc	
E317 Series	E317-15	dc	F, V, OH, H
	E317-16	ac and dc	
	E317-25	dc	H-Fillets, F
	E317-26	ac and dc	
E330 Series	E330-15	dc	F, V, OH, H
	E330-16	ac and dc	
	E330-25	dc	H-Fillets, F
	E330-26	ac and dc	
E347 Series	E347-15	dc	F, V, OH, H
	E347-16	ac and dc	
	E347-25	dc	H-Fillets, F
	E347-26	ac and dc	
E410 Series	E410-15	dc	F, V, OH, H
	E410-16	ac and dc	
	E410-25	dc	H-Fillets, F
	E410-26	ac and dc	
E430 Series	E430-15	dc	F, V, OH, H
	E430-16	ac and dc	
	E430-25	dc	H-Fillets, F
	E430-26	ac and dc	
E502 Series	E502-15	dc	F, V, OH, H
	E502-16	ac and dc	
	E502-25	dc	H-Fillets, F
	E502-26	ac and dc	

[a] *Where dc is specified, reversed polarity (electrode positive) is required.*
[b] *F, H, V, OH and H-Fillets are abbreviations indicating the various welding positions. Figures 1 and 2 show respectively groove and fillet welds in these different positions.*

Table 5.20

Classification numbers of electrodes for each series including usability designation and indicating type of current and position of welding

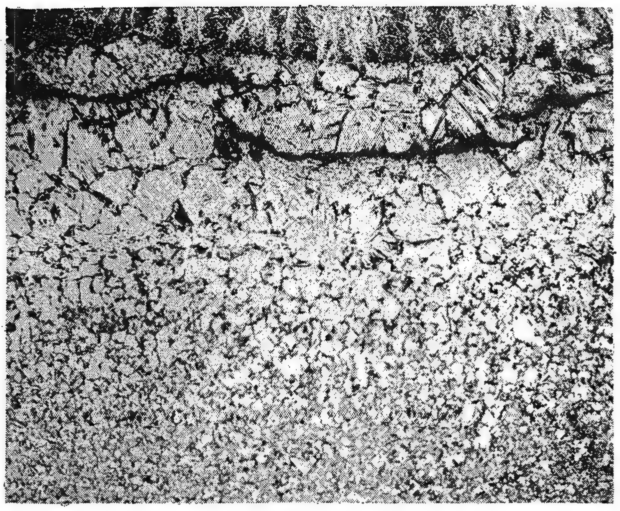


Fig. 5.6 - Underbead Cracking, 500x Nital Etch.

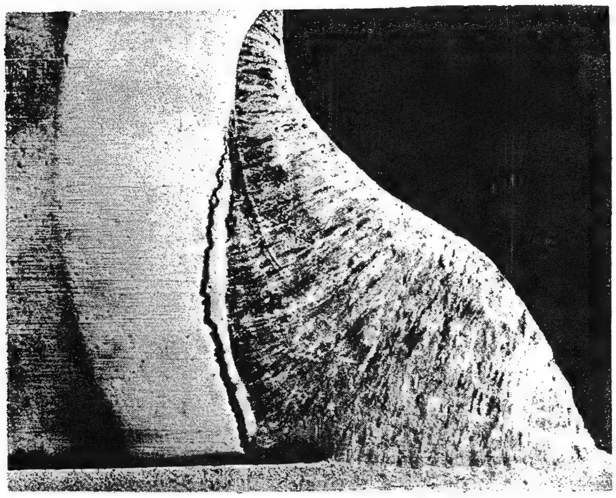
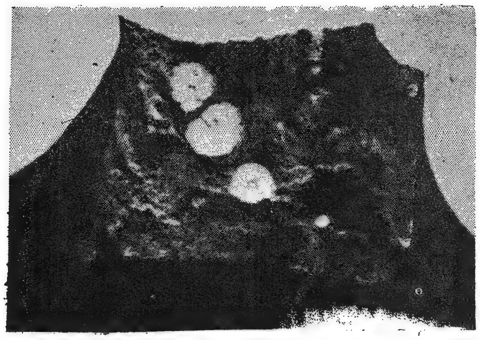
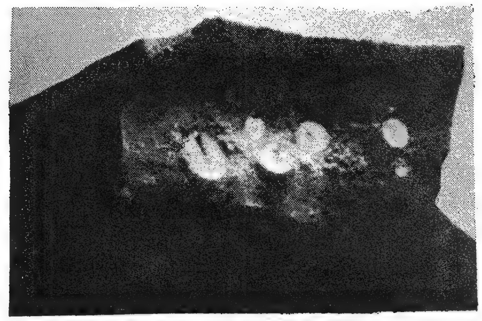


Fig. 5.7 - Underbead Crack in Hardened Zone During Fillet Welding x5

A



B



C

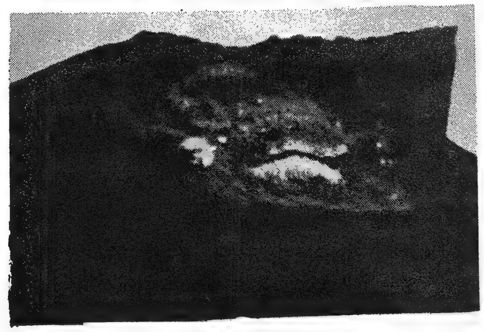


Fig. 5.8

Fisheyes on the surface of test bars, made from weld metal, caused by the metal containing (A) gas bubbles, (B) slag inclusions, (C) finely divided inclusions.

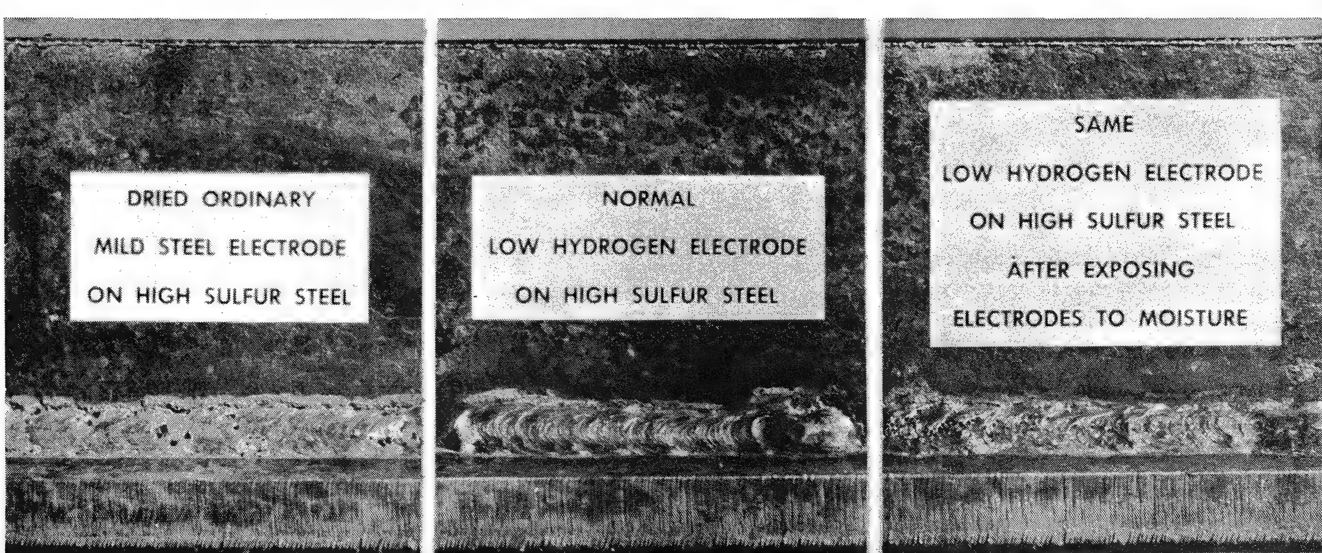


Fig. 5.9 - Horizontal Fillet Welds on Free Machining Sulphur Steel.

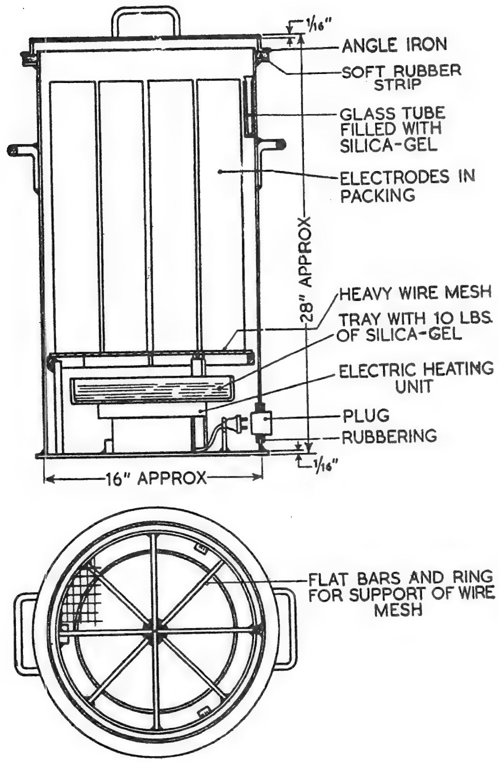


Fig. 5.10 - Dry Storage Bin For The Storage Of Arc Welding Electrodes.

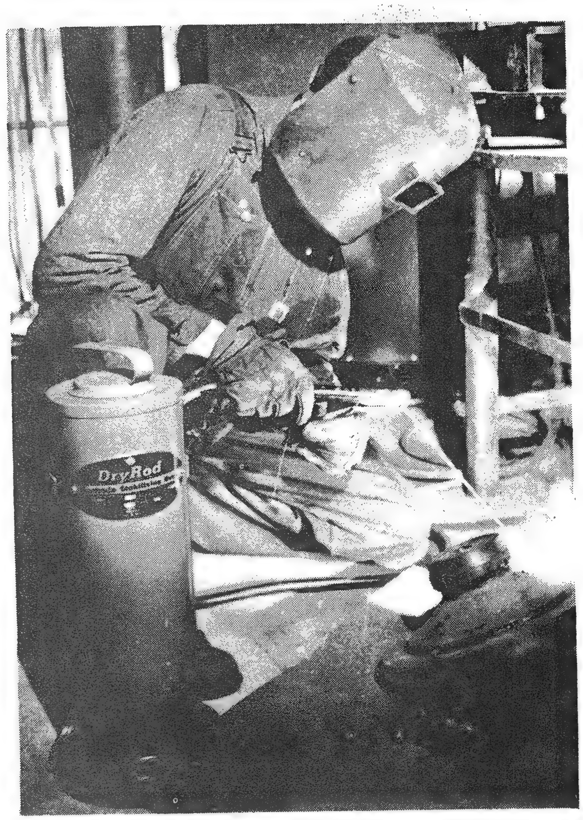


Fig. 5.11 - Type 10 Portable DryRod Oven.

Fig. 5.12 - Type 300 DryRod Oven

THE PREPARATION OF JOINTS FOR WELDING

The ease with which an operator is able to make an efficient and economical weld depends to some extent on the precision with which the plate or section edges are prepared, and the general accuracy of the joint fit-up. These points are important and any time, trouble and expense incurred in preparing a joint carefully will be well repaid in the quality and economy of the welding thereby obtained.

The five basic types of joints generally employed for arc welding have already been described and illustrated in Lesson 1, Fig. 1.1, but the preparation of the actual joint edge must be varied according to the thickness of metal involved, and the type and conditions of welding.

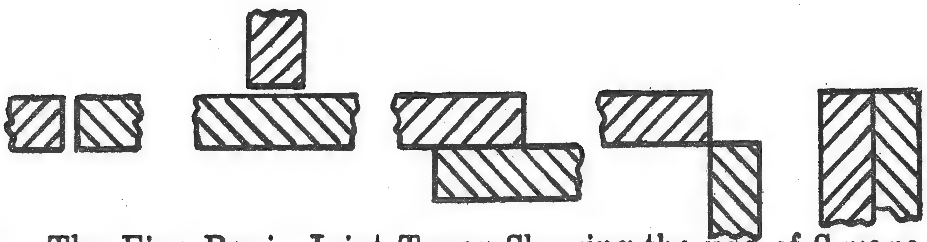
There are three forms of edge preparation - the square, the bevel and the J profile, and the principal ways in which these are employed for the various types of joint are shown in Fig. 6.1, page 6.2. It is important that these edges be prepared with reasonable accuracy, also that the preparation and the spacing, if any, between the joint edges be uniform throughout the length of the joint. Only in this way is it possible to ensure efficient fusion and uniform distribution of heat input to the joint, maximum economy of welding time and material, and a minimum of distortion and stress.

EDGE PREPARATION METHODS

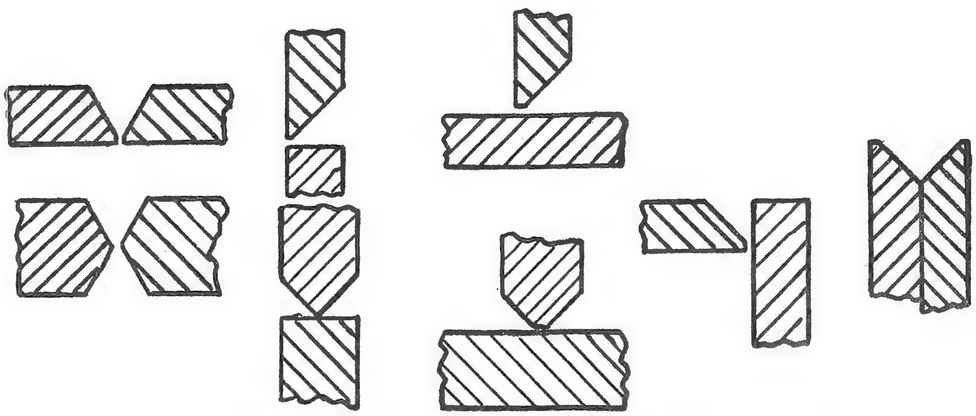
The three most commonly used methods of preparing plate edges are shearing, gas cutting and machining.

Shearing is certainly the quickest and cheapest method of preparing straight edges on plate up to 3/4" thick, and provided the sheared edge is free from cracks, excessive roughness or serious distortion, it is quite satisfactory for the preparation of square edges for welding or for the preliminary sizing of plates in preparation for subsequent bevelling. On all ordinary mild steels there should be no cracking or serious distortion if the shears are in good order.

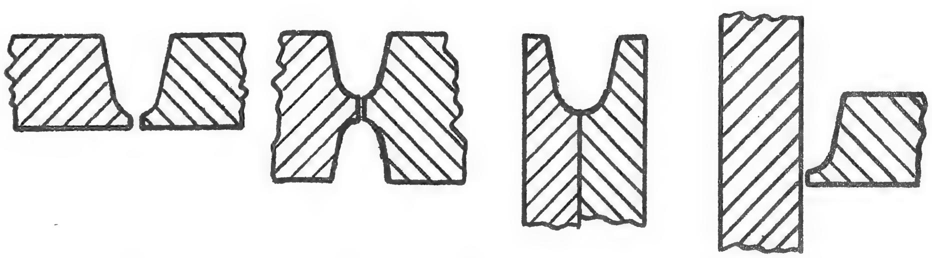
There are, however, restrictions to the use of shearing for certain classes of work, apart from any thickness limitations which may be imposed by the capacity of the shears. For example, shearing is not permitted for certain types of joints for oil storage vessels constructed to American Petroleum Institute specifications, and it is not permitted at all for pressure vessels constructed to A.S.M.E. and other classifications.



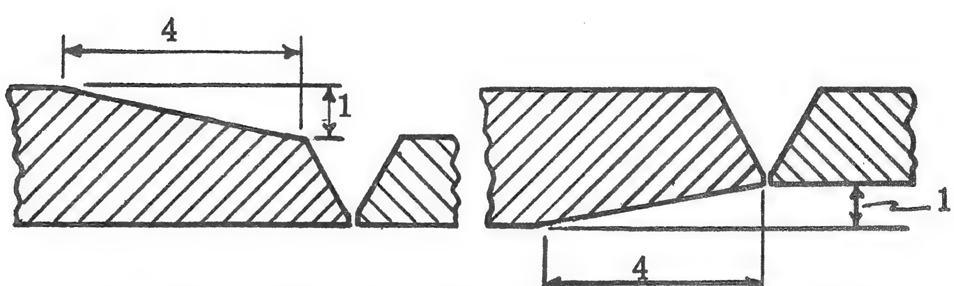
A. The Five Basic Joint Types Showing the use of Square Plate Edges



B. Some Joints Involving the use of Bevelled Plate Edges



C. Some Applications of the J Edge



D. Proportions of Slope for Equalizing Plate Thickness where the Difference in Thickness Exceeds 1/4"

Fig. 6.1
Various Types of Joints and Edge Preparations

Where shearing is allowed, rotary or serpentine shears may also be employed for edges which are curved or which do not provide a complete cut-off.

Machining is, of course, an excellent method of preparing any type of edge, but except for the highest quality work such as the pressure vessels just mentioned, these methods of preparation are usually not economical on account of the relative slowness of the overall operation and the amount of material handling involved.

Machine gas cutting is permitted by all classification authorities for most classes of work and is applicable to all kinds of square or bevel preparations on straight, shaped or circular edges. Moreover, the process has no detrimental effect on any mild or normal welding quality steels. Also, it is commonly used for preparing weldable air hardening steels, but in this case edges are usually ground back, after cutting, 1/8" or more. Preheating and post-heating may also be necessary with such steels to avoid edge cracking.

As far as cost is concerned, it is generally considered that gas cutting falls midway between shearing and machining. In the small shop particularly, the relatively low cost of the gas cutting machine and its ability to deal equally well with any plate thickness is a considerable advantage.

CHOICE OF METHOD

Strictly speaking, with the foregoing remarks in mind, these three methods of edge preparation should not conflict in any way, the method employed depending upon the equipment available and the classification to which the work is being constructed.

For low cost and high speed, shearing will be used for square edge preparation, also for the preliminary sizing of plates before bevelling by gas cutting.

Where shearing is not permitted, or is not possible, gas cutting is the next alternative for all types of edges.

Where either shearing or gas cutting is permitted, machining would not be considered on account of cost. As previously mentioned, however, machining is sometimes specified for certain high duty requirements, and for the reduction of thick edges. In such cases the cost factor becomes a matter of minor importance.

General experience shows that, normally plate edge distortion is a negligible factor with either shearing or gas cutting. Where, however, narrow strips of plate are to be prepared, it is possible that gas cutting will produce slightly more distortion than shearing. Usually, any such distortion is not sufficient to cause any difficulty in welding. If it is, it will be desirable to straighten the edge in order to ensure an accurate fit-up.

Where gas cutting is employed for cutting narrow strips of plate, distortion can be reduced, if not eliminated, by cutting the opposite edges of the strip simultaneously, i.e. by using a machine fitted with two torches. This method also ensures that both edges will be parallel (see Fig. 6.2 below).

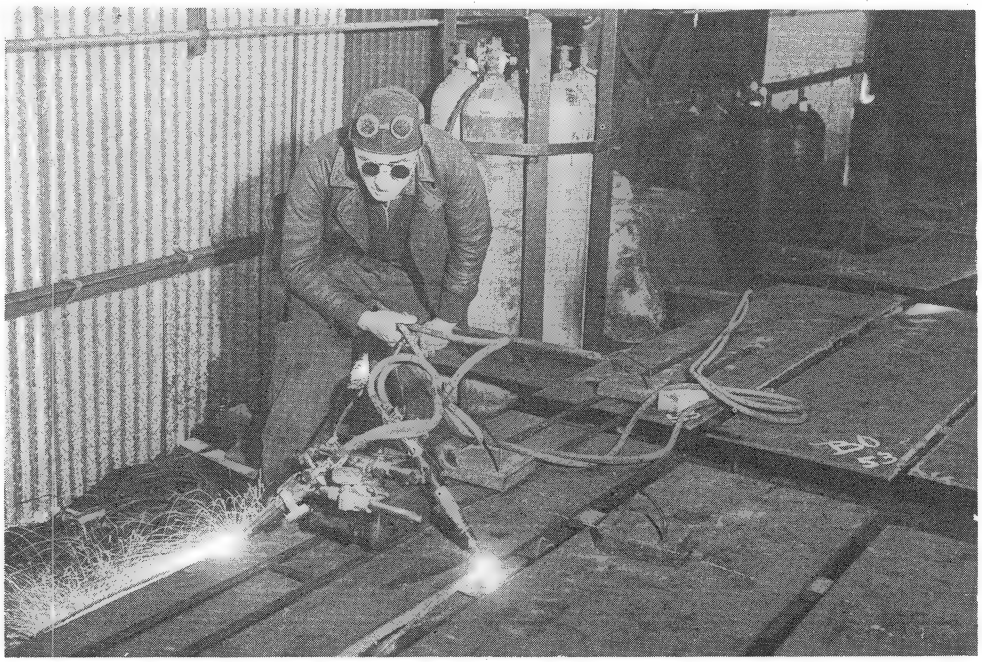


Fig. 6.2
A Machine Fitted With Two Torches for Bevelling Two Parallel Plate Edges Simultaneously.

Since shearing and machining require little or no explanation, the following notes apply particularly to gas cutting.

There is a tendency in some shops to be content with low standards of accuracy and finish for gas cutting. This is most undesirable and cannot be other than uneconomical and detrimental to the subsequent welding of the joint. It is hoped that the information given here will emphasize the need for precision in this respect, since inaccurate preparation and poor fit-up will increase the cost of the job considerably.

BASIC PRINCIPLE OF OXYGEN CUTTING

Briefly, the basic principle of oxygen cutting depends upon the simple fact that steel at red heat will oxidize rapidly or 'burn' where a jet of oxygen is directed onto it.

The ordinary cutting torch enables this to be done by providing both a heating flame and a pure oxygen jet - each with its own controls - the heating flame being used chiefly to preheat the steel where the cut is to be started, after which the oxygen jet does the cutting.

Only a small area needs to be preheated for starting the process since as soon as oxidation commences, the combustion of the steel produces a very intense local heat. This further preheats the metal around the oxidation point, enabling the oxygen jet to pierce almost any thickness of steel, or to make a cut in whichever direction the torch is moved. After the cut has started, the main function of the heating flame is to keep the oxide fluid (so that it will leave the cut easily) and to compensate for heat losses, especially at the upper edge.

The metal is not melted. The process depends entirely on the combustion (that is, burning) of the steel in the path of the oxygen jet. On mild and normal welding quality steels, the process has no detrimental effect on the metal* and there is no need to machine the cut surface before welding.

Smoothness of the cut edge is an important feature and this depends almost entirely on the uniformity and precision with which the torch is moved. The movement may be made with the torch held in the hand (i.e. manual cutting) or it can be mechanically propelled - machine cutting.

MANUAL CUTTING

Manual cutting is usually undesirable for the preparation of joint edges, owing to the inaccuracy and irregularities of movement inseparable from hand control. Unless the torch is carefully handled, such edges may be difficult to clean since their roughness tends to trap oxide. Any excessive roughness or adhering oxide should be ground off before the joint is set up for welding.

*It is only when the carbon content of the steel exceeds about 0.25% or other air hardening elements are present, that there is any likelihood of appreciable hardening or cracking due to the rapid heating and cooling of the cut edge.

However, for the preparation of structural sections and some types of short or irregular shaped plate edges, manual cutting is often employed. In such cases every effort should be made to minimize irregularities of movement. By adopting a comfortable position with one hand resting on the metal surface and supporting the nozzle end of the torch, and the other controlling the cutting oxygen valve, many operators are able to make reasonably smooth freehand cuts. There are, however, also sundry aids available which will improve cutting accuracy. For instance, a nozzle guide will keep the nozzle tip at a uniform distance from the metal surface and, on some types of guides, the angle of the nozzle is adjustable for the cutting of bevels. For straight edges a guide consisting of a piece of flat bar or angle iron should be laid on the metal surface so that the nozzle or guide can rest against it, enabling a fairly true straight edge to be produced. For cutting circles a radius rod should be used. Such a rod is shown here being used in conjunction with a small variable speed traversing carriage running directly on a ring plate path (see Figs. 6.3 and 6.4 below).

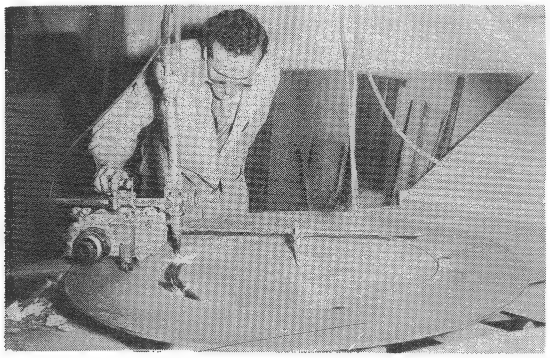


Fig. 6.3
Cutting Discs by Means of a Portable Oxy-Acetylene Flame Cutting Machine Using a Ring of Plate as a Track and a Circle Cutting Attachment.

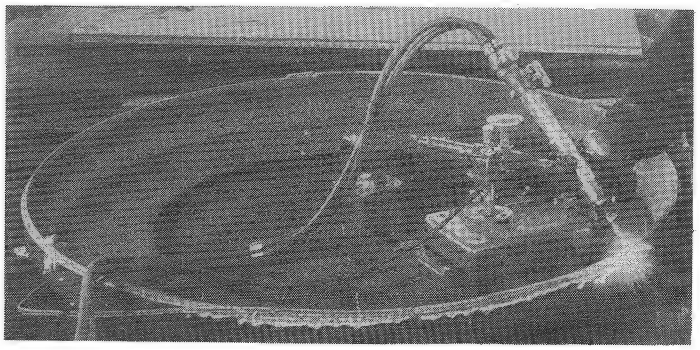


Fig. 6.4
Machine Arranged for Cutting Circular Edge of Pressing or Forging

MACHINE CUTTING - TYPES OF MACHINE

Machine gas cutting is an entirely different proposition. In this case the torch is rigidly held and propelled at a uniform speed, so that - provided the track on which the machine runs is clean and free from irregularities - accurate cuts as smooth as a saw cut are produced. Such edges need no machining or other finishing, and the oxide should come away from the cut surface easily (e.g. by wire brushing) leaving it clean and ready for welding.

For straight edge preparation or plate trimming, two types of machine are available - (a) a simple type which runs on a track laid directly on the plate surface, (as in Figs. 6.5 and 6.6) and (b) a more elaborate fixed type in which the track is supported independently on the plate (as in Fig. 6.7, page 6.8).

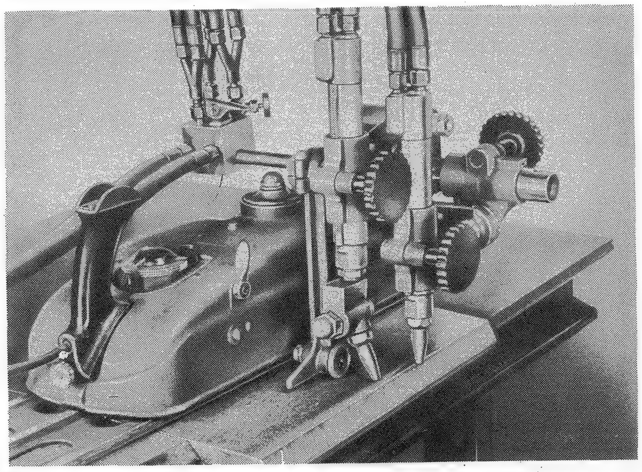


Fig. 6.5
Straight Line Cutting Machine Using Portable Track and Fitted With Two Torches; Set Up for Cutting Bevel and Nose.

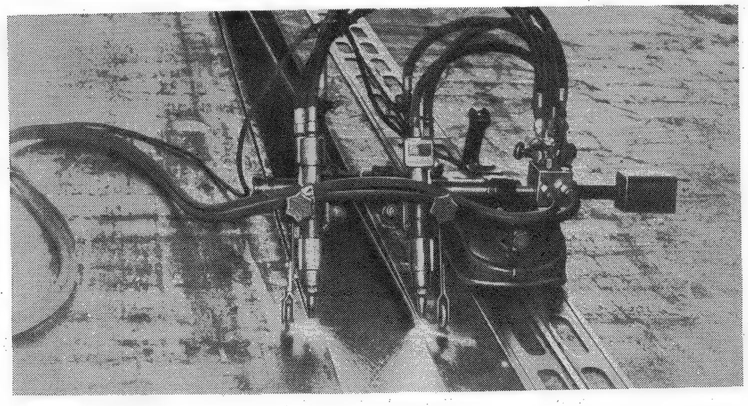


Fig. 6.6
Dual Torch Mounting for Cutting Matching Edges on Two Plates in Shipyard Use.

The first type is most generally employed, since the equipment is readily portable and, in the case of large plates, it is usually easier to move the machine than the plate. On the other hand, the track must be carefully set up for each cut. Where the machine is independently supported, all material to be cut must, of course, be brought to the machine and set up, but the mechanical accuracy of the machine is not disturbed. Some shops have provided a fixed right angle track arrangement, on which two portable machine units operate independently, for preparing two adjacent edges of plates, as shown in Fig. 6.7 below. Such an arrangement reduces plate handling and saves time. The two cuts can be made simultaneously and the fixed right angle location of the tracks increases the cutting accuracy.

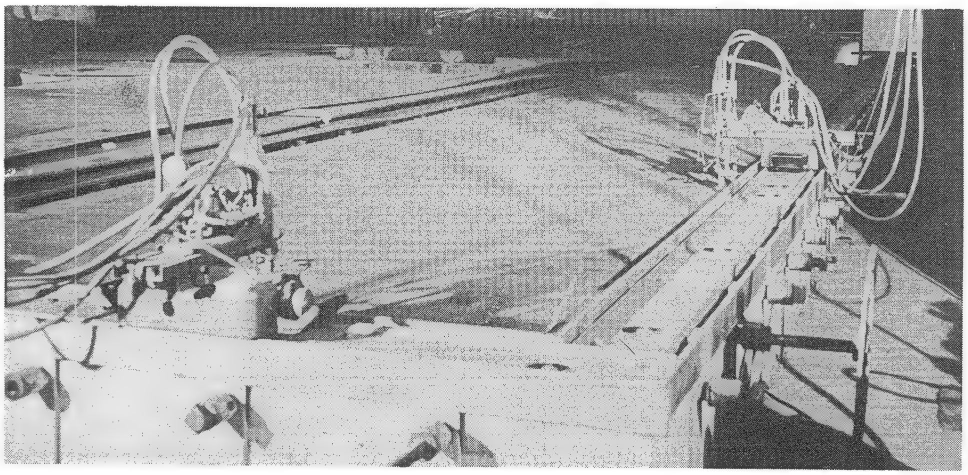


Fig. 6.7
Special Arrangement of Right Angle Track With Two Machines to Enable Two Plate Edges to be Cut Quickly and Accurately.

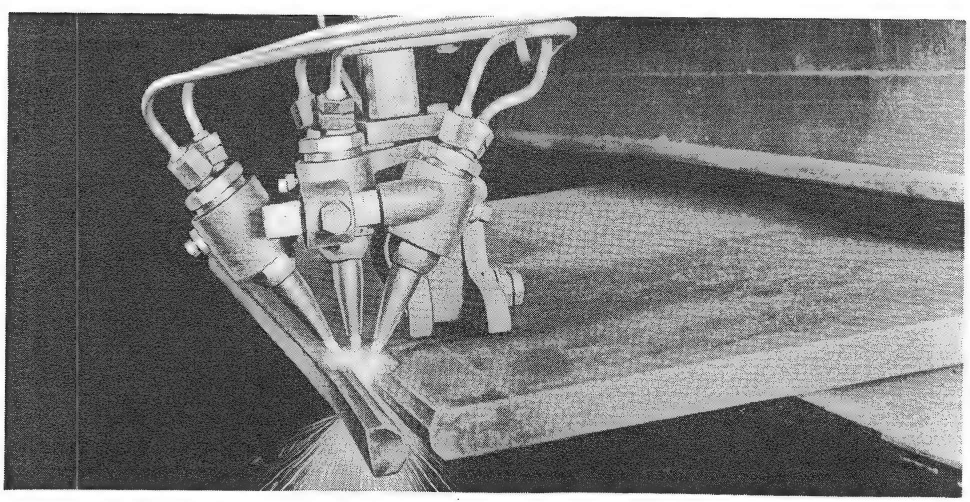


Fig. 6.8
Plate Edge Preparation Unit for Simultaneous Double Bevel and Nose Cutting.

In all cases the length of cut is limited only by the length of track, gas hose and electric cable.

For cutting square edges and bevels without a root face, or bevels with a root face if the square edge has been prepared by a previous gas cut or by shearing, a machine fitted with one torch will be suitable. Double bevels may also be prepared by turning the plate over. For preparing a bevel with root face, or a double bevel at one cut, the machine must be fitted with two torches (See D and E Fig. 6.9, page 6.11). Machines fitted with three torches have also been developed for cutting two bevels and nose at one cut. Such a machine is shown in Fig. 6.8, page 6.8.

In some machines the torch holding fixture is provided with a plate riding device in order to ensure that the nozzle tip is maintained at a uniform distance from the plate surface, regardless of any undulations there may be in it. This is a useful feature for bevel cutting since, if the nozzle distance varies, the cut edge will not be straight, and the joint will not fit up accurately. In the absence of such an arrangement the operator must adjust the cutter height while the machine is travelling, in order to maintain a uniform distance.

SETTING UP FOR CUTTING

The plate to be cut should have ample support so that there will not be any tendency for it to move during cutting - due, for example, to change of weight distribution caused by the removal of metal. It is bad practice to lay plates directly onto the top of the tee bars which generally form the cutting table. Conical, or round ended, steel or cast iron studs which are slotted and supported by the tee bars, provide a more readily adjustable supporting means and avoid cutting damage to the tee bars.

The cutting line should be chalked on the plate and centre punched; in order to help the cutting machine operator to set up his machine it is also useful to mark another line to which he can set the machine track. The path of the cut should be clean, any scale, paint or other surface dressing being removed before cutting is commenced. Hand traversing of the machine along the line of cut with the heating flame alight will usually crack off any surface scale, and wire brushing will then produce a clean metallic surface. Alternatively, the cutting path may be heated with a welding blowpipe flame and then wire brushed.

As previously mentioned, smoothness and uniformity of the cut edge is an important factor in securing an accurate cut and a good fit-up. Track and driving gear should, therefore, be free from any irregularities which will affect the smooth running of the machine, and the site should not be subject to vibrations from other machines. Also the gas hose and electric cable should be suspended so as to avoid any drag or pull on the machine.

BEVEL CUTTING

There are several reasons why bevel cutting conditions differ slightly from those employed for square edge cutting. Setting the nozzle at an angle increases the depth of metal to be penetrated, thus necessitating a slight increase in oxygen pressure and a reduction in cutting speed. Moreover, when set at an angle most of the heat from the flame goes in the direction in which the nozzle is inclined, that is, towards the part which is usually scrap or discarded metal.

This can be appreciated by reference to the sketches which Fig. 6.9, page 6.11 comprises.

Obviously these conditions are intensified as the nozzle angle increases. The usual limit of angle for satisfactory cutting is about 45^{o}, in fact under some conditions difficulty may be experienced in making a satisfactory cut at this angle, due to the reduced heating influence of the flame. In such cases some benefit may be obtained by providing additional heat from a welding torch, attached to the machine in such a way that its flame is directed onto the 'plate' side of the cut.

Where angles greater than 45^{o} from the vertical are required - as for example in making the 4 to 1 slope usually specified for the reduction of edges of thick plates - the cut may be made from the plate edge instead of from the surface, as shown at H in Fig. 6.9, page 6.11.

When the plate is first gas cut to size with square edges, the bevel cut should be made while there is still considerable heat left in the edge from the previous cut. Where the plate is first sheared or gas cut to size the second cut should leave a slight nose at the bottom of the bevel as a witness of the original correct size of the plate; the nose also assists in setting up and spacing the edges.

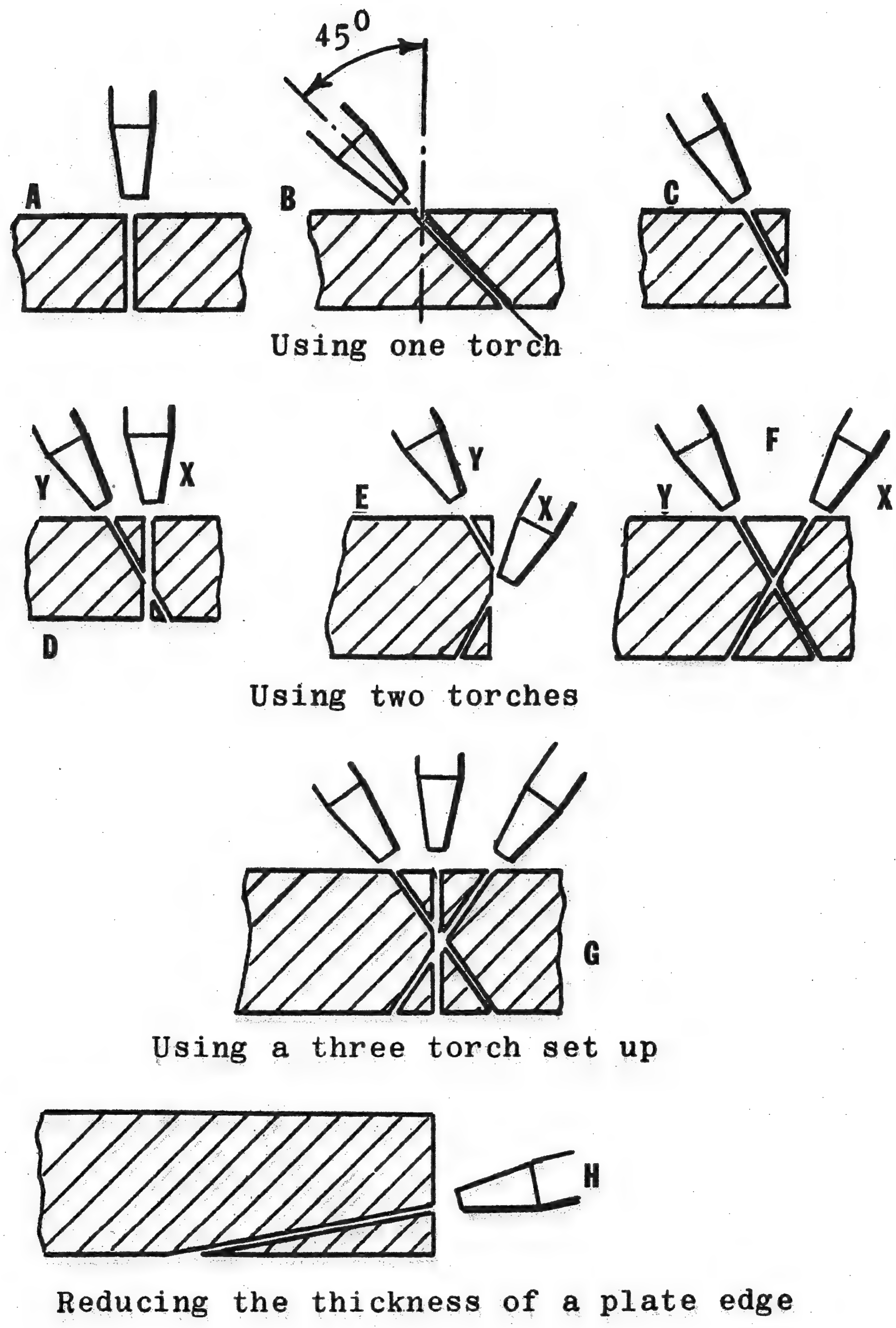


Fig. 6.9

The Employment of Oxygen Cutting for
Preparing Square and Bevel Edges

Unless the torch height is automatically controlled when the bevel is cut from a square edge, the operator may need to adjust the nozzle height occasionally in order to keep the nose at a constant depth.

On plate over 3/8" thick, where shearing is not employed for sizing the plates, the necessity for making two separate gas cuts for making the bevel and nose may be avoided by mounting two torches in the machine, as shown at D in Fig. 6.9, page 6.11. Torch X should be about 2" in front of Torch Y.

Two torches may also be used for making a double bevel and nose from a previously sheared or gas cut edge, as shown at E; again Torch X should be about 2" ahead of torch Y. Although machines fitted with three cutters have been developed for forming both bevels and the nose simultaneously, as shown at G, such an arrangement is generally limited to plate under 1" thick, as the high heat input to the plate edge tends to melt the nose.

Plate Thickness ins.	Tip Size (Drill sizes)	Oxygen Pressure P.S.I.	Cutting Rate ins. per min.
1/4	62/58	30/20	21
5/16	60/57	35/25	20
3/8	57/55	35/25	19
1/2	56/54	40/30	17
5/8	56/53	40/30	16
3/4	55/53	45/35	15
1	55/53	55/45	14
In the case of the oxygen pressures given above, the higher pressures would be suitable for the smallest nozzles and vice versa.			

Table 6.1

Approximate Guide for Machine Cutting Square Edges in Steel Plate

ADJUSTMENT OF CUTTING CONDITIONS

The correct adjustment of the heating flame, oxygen pressure, and cutting speed contribute materially to the smoothness of the cut and the ease with which the scale is removed after cutting. Usually the same size nozzle can be used for square or bevel cuts on any thickness.

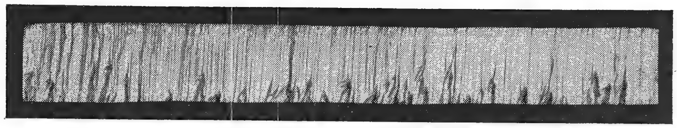
The torch and cutting machine manufacturers generally provide cutting data which will guide the user as to the tip sizes, gas pressures and cutting speeds to be employed for different thicknesses of steel. However, slight modifications to gas pressures and cutting speed may be found desirable to suit individual conditions or requirements. In fact, the standard of quality of cut, and the cutting conditions required to produce it, are best established by making trial cuts on scrap plate.

A specimen table of nozzle sizes, oxygen pressures and cutting speeds for making square edge cuts on various plate thicknesses is given in Table 6.1, page 6.12.

For the reasons previously mentioned, slightly more preheat is usually needed for bevel cutting than for straight edge cutting, but with either type of cut the flame should be so adjusted that there is no melting of the top corner of the cut. Where the nozzle has four preheat holes, the line of cut should lie between each pair of holes, i.e., so that there are two preheat flames on each side of the cutting line, in order to obtain the maximum benefit from the flames.

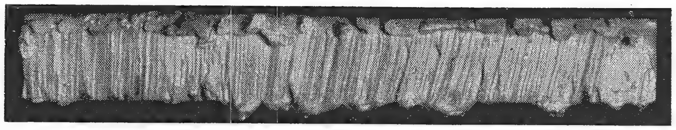
The distance between the tip of the nozzle and the metal surface should be carefully regulated: between 1/4" and 3/8" is usually about right. If the nozzle is too far away from the metal the oxygen jet will spread and make a wide cut. If it is too close the top corners of the cut may be melted and there is the possibility of the nozzle being fouled by scale or burnt by reflected heat.

Excessive gas pressure is quite unnecessary and often leads to rough cuts, apart from the waste of gas involved. As previously mentioned, square cuts can be made at higher speeds than could be used for bevel cutting, and the most economical cutting conditions are reached when the speed is such that the cut 'drags' slightly, i.e. when the oxide stream on the underside of the plate lags behind the top of the cut. For either square or bevel edges a certain amount of 'drag' is not objectionable provided it does not distort the cut surface - as it may do with excessive speed or oxygen pressure.



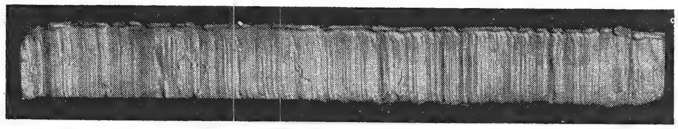
Cutting speed too slow. Make preheat flames longer - should be about 1/4 in. long.

Gouging at bottom.



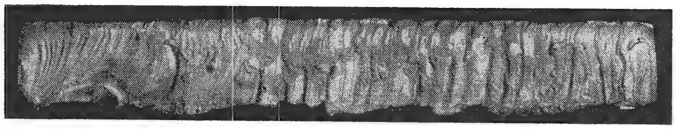
Preheat flames are too long - should be about 1/4 in. long. Nozzle may be too close.

Cut irregular, too much slag, top surface melted over.



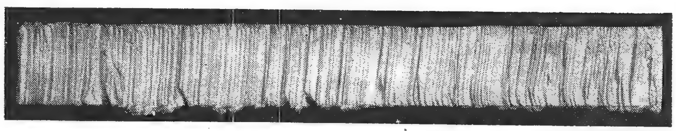
Speed too slow. Increase the oxygen pressure - check your pressure chart.

Top edge melted over.



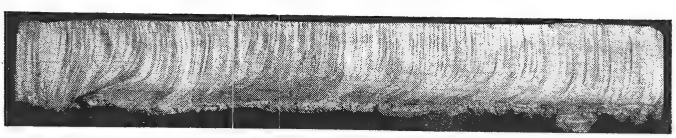
Cut down the oxygen pressure - check your chart for correct pressure and nozzle size.

No control of the cut



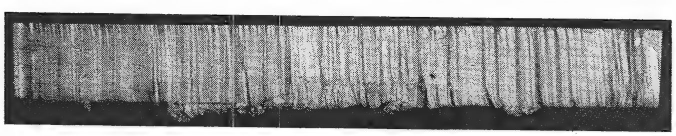
Increase your cutting speed.

Irregular kerf lines are emphasized



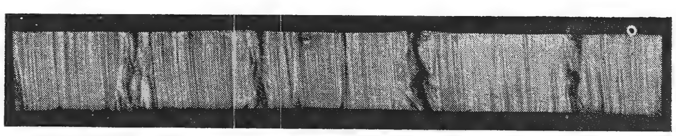
Decrease your cutting speed. Nozzle may be too high.

Cut edge is irregular - rake to the lag or kerf lines.



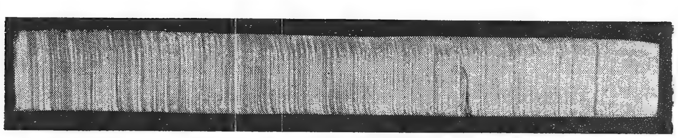
Use your left hand as pivot - right hand guides the blowpipe. Movements must be smooth and steady.

Cut edge wavy and irregular



Preheat - and press down cutting - oxygen lever slowly just as when starting cut

Gouges where cut was lost and restarted



This is a good cut in 1 in. plate. The edge is square and the drag lines are vertical and not too pronounced.

Fig. 6.10
Flame Cutting Faults

Faults in cuts and their causes (other than those due to mechanical faults) are shown in Fig. 6.10, page 6.14.

EQUIPMENT MAINTENANCE

The main items requiring regular maintenance are the cutting tips, and particular care should be paid to their cleanliness and the method by which they are cleaned. It is of little use to achieve accuracy in other respects if the tip bore is obstructed by scale or burrs, or distorted by careless cleaning, since the smoothness of the cut edge will be affected by any distortion of the oxygen jet. Nozzle holes should be cleaned only with a drill of the correct size, and no attempt should be made to ream the holes by rotating the drill; use an up and down motion only. If a suitable drill is not available use brass, not steel, wire.

The gas pressure gauges and speed indicator on the machine should also be maintained in good order so that reasonably accurate pressure and speed adjustments can be made and repeated whenever required.

"SPECIAL CUTTING APPLICATIONS"

"GOUGING"

Gouging is a variation of the normal gas cutting procedure intended for the removal of metal from steel surfaces, and is often used instead of chipping. It may be performed by hand or machine; when applied manually, it is used for the removal of surplus metal, surface defects or for grooving out the root of a weld in preparation for the reverse side sealing run. When applied by machine, the most useful application is for the preparation of the J edge as described below.

The only special equipment required is a series of specially designed nozzles which may be fitted to the normal hand or machine cutting blowpipe. The blowpipe is held so that the nozzle makes an angle of 5^o to 10^o with the metal surface - a slightly greater angle may be necessary for starting the groove, as shown in Fig. 6.11. The depth of the groove

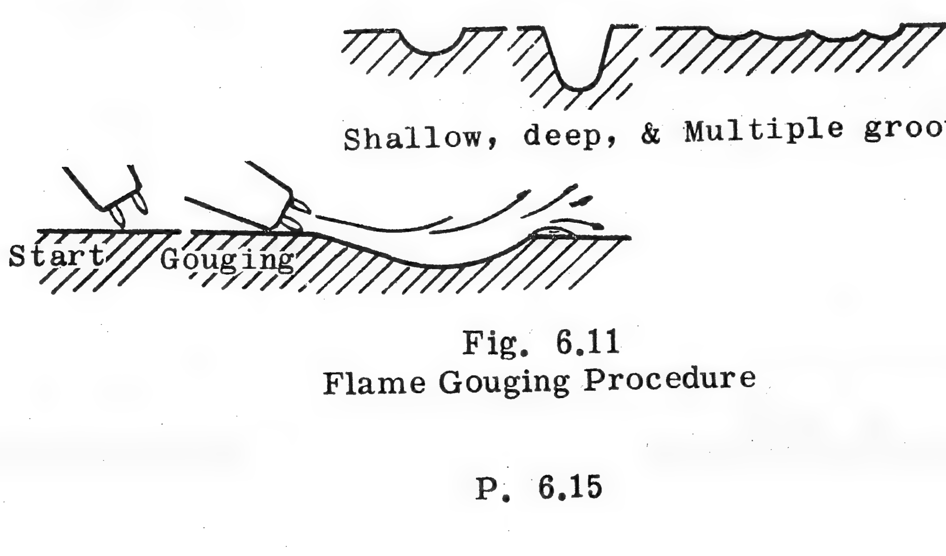


Fig. 6.11
Flame Gouging Procedure

may be regulated by varying the speed of travel and by altering the angle between the nozzle and the work.

An alternative to gouging by gas is the Arc Air torch to which reference has already been made on page 3.23 under Carbon Arc Cutting. The process is equally satisfactory for both ferrous and non-ferrous metals.

J PROFILE

The U shaped groove was originally developed in order to reduce the amount of weld metal which is required to fill a normal angle Vee groove on thick plate, e.g. over 1" thick. More recently, the introduction of the submerged melt process requiring only a very small Vee angle has almost entirely obviated the need for this type of preparation. There are, however, sundry applications for which it is still employed.

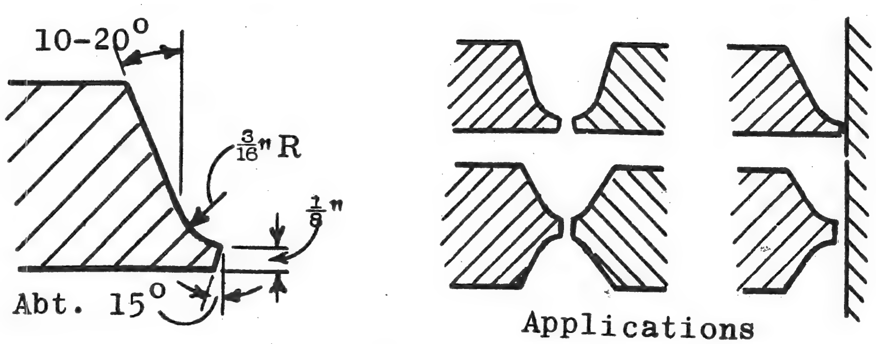


Fig. 6.12
The J Edge

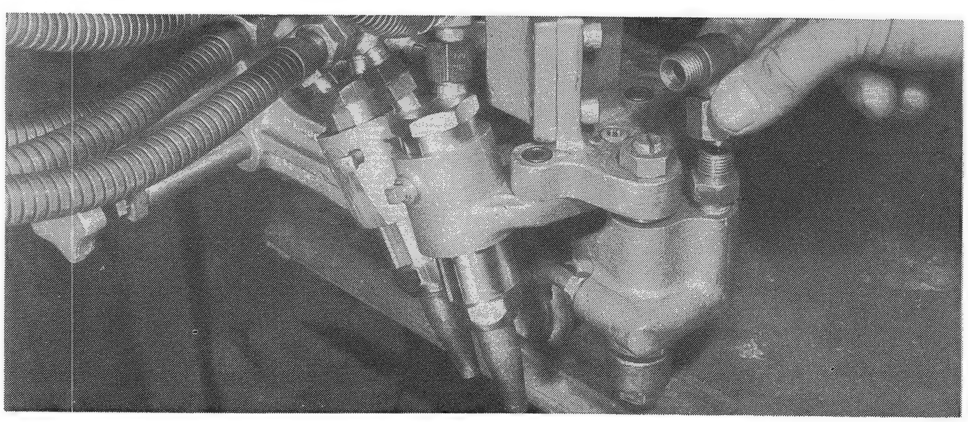


Fig. 6.13

Special Two-Torch Set Up for High Speed Square Edge Plate Trimming. The Torch Holder is Fitted With a Plate Riding Wheel Which Ensures a Uniform Distance Between Nozzle and Metal Surface Throughout the Cut.

In such cases each edge should be prepared as near as possible to the proportions shown in Fig. 6.12. The preparation may be made by planing for straight joints or turning for circular joints, or, on plate 3/4" thick and over, it is possible to produce the profile by flame machining. One way of doing this is to use a straight line cutting machine fitted with an ordinary cutting torch and a second torch fitted with a gouging nozzle.

The finished edge must be produced in two steps. First, an under bevel cut of about 14 degrees is made by the ordinary cutting nozzle alone, then the gouging nozzle is brought into position to produce the concave groove. The positioning of the gouging nozzle must be accurately adjusted according to the plate thickness and the shape of profile required. It is also desirable that the gouging operation should follow the bevel cut as quickly as possible in order to utilize the heat remaining in the edge; any adhering slag must be completely cleaned off from the bevel surface prior to the gouging operation.

HIGH SPEED EDGE TRIMMING

One method of attaining very high cutting speeds for square plate edges, is to carry out the operation in two cuts which are made simultaneously, the machine being provided with two torches, as shown in Fig. 6.13, page 6.16. The first torch is fitted with an oversize nozzle inclined at a forward angle to produce a rough severing cut at high speed; this operation preheats the plate edge so that, at the same time, the rear or trailing nozzle (which is offset 1/16 to 3/32 inch) trims off the rough edge, producing a final edge smooth enough for welding. The saving in labour, plus overhead, more than makes up for the slightly higher gas cost per cut.

MULTI-TORCH AND STACK CUTTING

A number of relatively thin plates may be piled one on top of the other, and then cut as a single piece of steel. This is a useful method for producing a number of parts of identical shape and is called stack cutting.

For successful stack cutting it is essential to fully press the sheets or plates together so that air spaces are entirely eliminated. Special clamps are usually employed and these may be supplemented by the use of weights or by welding the plate edges together by means of a series of vertical welds from the top to the bottom of the stack.

Fig. 6.14 illustrates the use of clamps and weights combined. It is not usually desirable for the individual plates to be more than 5/16" thick, otherwise there may be difficulty in clamping the stack tightly; there is really no limit to the total thickness of the stack, but two to four inches is usually most convenient.

Obviously, the nozzle size, oxygen pressure and cutting speed should be adjusted as for a block of steel of the same thickness as the stack.

Fig. 6.15 shows a number of torches mounted on a radial arm. Each torch traverses an identical path and cuts out an identical part. Elaborate machines of this type are available for mass production.

CUTTING STAINLESS STEEL

Until recently, it was difficult to make reasonably accurate or smooth gas cuts on stainless steel; this was due to the formation of solid, high melting point oxides of the stainless elements (mainly chromium) which prevented the establishment of the oxidation reaction by which ordinary steels are cut.

The problem has been largely overcome by the development of two new processes. One introduces an iron powder into the oxygen stream and the other a non-metallic flux. Both are successful and result in cuts as clean and smooth as those produced in mild steel. Moreover, on titanium and columbium stabilized steels the stainless qualities of the cut are not impaired.

CUTTING NON-FERROUS METALS

The above mentioned iron powder method can also be used for cutting copper, bronze and various alloys with a low ferrous content. Cast iron can also be more readily cut by this means.

BIBLIOGRAPHY

1. Welding Handbook - American Welding Society, 33 West 39th St., New York 18, N.Y.
2. Oxygen Cutting by G.V. Slottman and E.H. Roper, The McGraw-Hill Book Co. Inc. 330 West 42nd St., New York 36, N.Y.
3. Oxy-Acetylene Cutting - International Acetylene Association, 30 East 42nd Street, New York 17, N.Y.

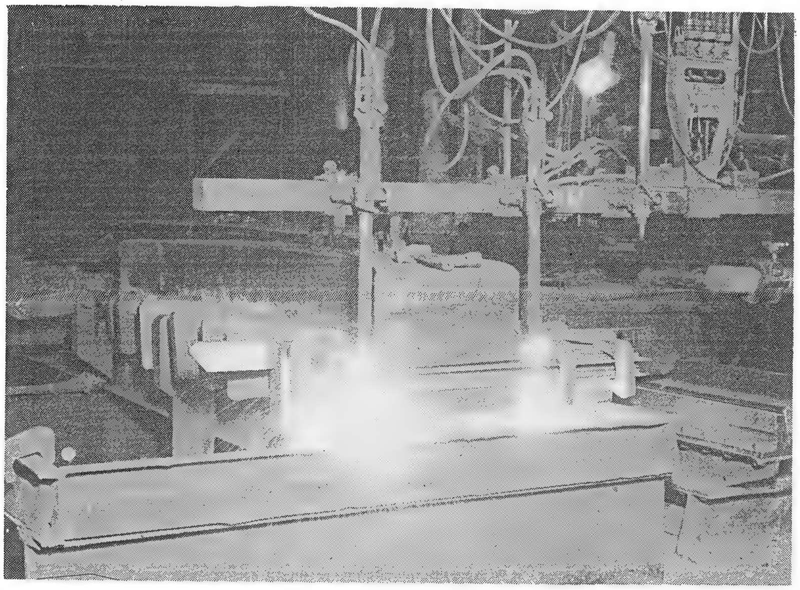


Fig. 6.14

Stack Cutting With Two Torches, Using a Heavy Slab to Compress Stack in Conjunction With Special Edge Clamps.

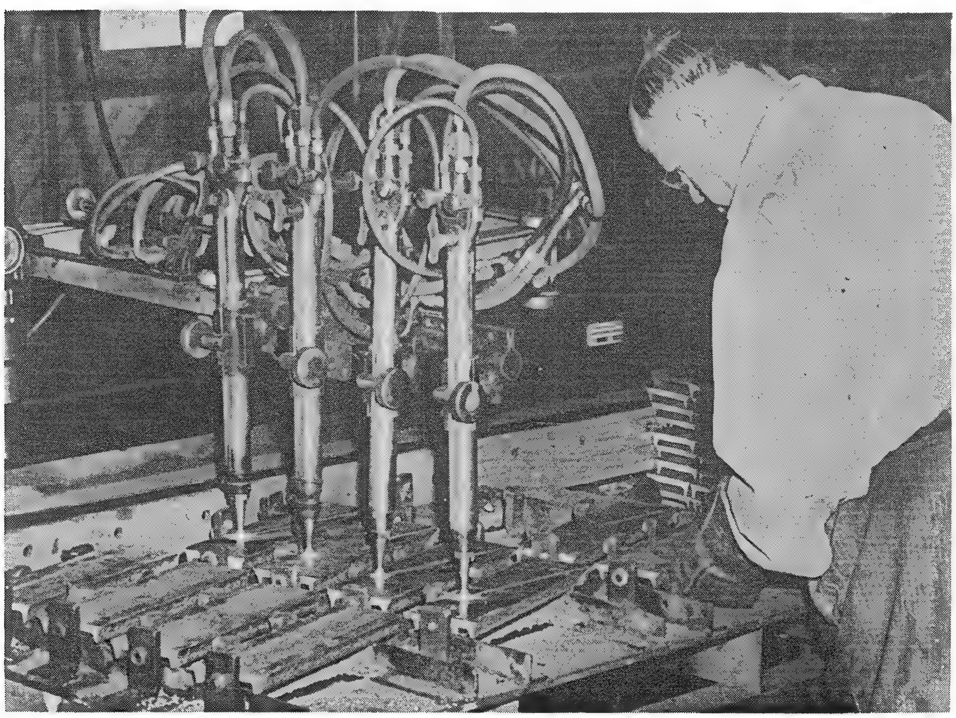


Fig. 6.15

Multi-Torch Flame-Cutting of Parts for Agricultural Machinery

HEALTH AND SAFETY PRECAUTIONS

Although all ordinary welding and cutting equipment is made to be safe under normal usage conditions, operators should never be allowed to forget that carelessness and neglect of safety rules may lead to the creation of dangerous conditions.

Familiarity with equipment or a process is often liable to lead to contempt or oversight of the precautions which are now recognized as being essential for the safety of users and their associates.

It is therefore the duty of those responsible for welding and cutting operations and the use of the requisite equipment to see that operators are familiar with all the safety rules concerned. This is not a matter on which there need be any ignorance as ample literature on the subject is available, to which references are made at the end of this lesson. Moreover, the equipment manufacturers issue working instructions and safety precautions and these should be studied by both operator and supervisor before the plant is put into operation. Where wall notices or charts are available they should be displayed where operators and others can see and read them. Finally, careless practices of any sort should be vigorously discouraged.

This lesson enumerates only the more important factors relating to safety. Those students who are, or may be held, responsible for safety conditions should thoroughly familiarize themselves with the various codes and other literature on the subject, most of which is hereto appended as a bibliography.

GAS CYLINDERS

Although oxygen, acetylene and other compressed gas cylinders are made to withstand normal usage without risk, dangerous situations may arise if they are carelessly handled. Operators should be instructed as to the broad characteristics of the gases which cylinders contain, for example:

Oxygen cylinders are filled to a pressure of about 2000 lbs. per square inch. Oxygen itself does not burn, that is, it is not combustible. It is however the essential element necessary for combustion and pure oxygen in combination with any type of inflammable material may - under favourable circumstances - produce very intense combustion. Therefore the use of such highly combustible substances as oil or grease on valve fittings and screw threads or in pressure regulators is likely to be highly dangerous and must be prevented at all

times. Also, leaks are dangerous in storage places and similar confined situations because they raise the oxygen content of the local atmosphere and increase the fire risk.

Acetylene, on the other hand, is a very inflammable and readily explosive gas. Leaks must therefore be avoided since almost any quantity when mixed with air forms a highly explosive mixture which may be detonated by a spark, heat or even shock. The cylinders are not filled to such a high pressure (about 250 lbs. per square inch) as are oxygen cylinders but they are heavier because they are filled with an absorbent material. On account of this additional weight extra care in handling is essential. Safety or fusible plugs are provided on acetylene cylinders to function only in case of fire in the cylinders or in the event of cylinders being trapped in a fire. The fusible plugs melt at about 250°F., so boiling water, steam or flame must never be used to thaw frozen valves.

Handling and Using

Cylinders must never be dropped; attention should therefore be given to the method of handling them in and around the workshop, on a field site, etc. For lifting by crane, proper cradles should be employed. Never use rope slings or magnets.

During transportation, either on railway or road vehicle or hand truck, they should be properly secured so that there is no risk of their falling or striking each other violently.

Do not allow cylinders to be handled by operators with greasy hands, gloves or overalls.

Whenever cylinders are being handled or moved from one site to another the pressure regulator should be removed and the valve protection caps should be in place. Do not allow cylinders to be handled by means of the pressure regulators.

Cylinders should be handled and used in an upright position and secured by chain, clips or rack so that there is no risk of their being knocked over.

They should not be placed where there is any risk of contact with third rails, electric cables, oil or grease.

Heat will cause the gas pressure in the cylinder to increase with corresponding increase of risk. Therefore, cylinders should not be located near furnaces, boilers, radiators or combustible material; where slag, sparks, flames or heat from the operation will reach them, or on the direct rays of the sun without protection.

Never allow cylinders, even if empty, to be used as rollers or work supports.

When a special wrench is required to operate the cylinder valve, that wrench should be left in position on the cylinder so that the gas can be quickly turned off in case of emergency.

Storing

Store oxygen separately from acetylene and other fuel gas cylinders and in well ventilated storage places. Do not have combustible material of any sort in the same storage place and, as mentioned above, do not store near radiators, boilers or any other source of heat. Store sheds or rooms should be of fire resisting construction.

It is recommended that when cylinders are stored inside a building the total gas capacity should not exceed 2000 cubic feet or 250 pounds of liquified petroleum gas, i.e.- about eight cylinders. When the storage quantity exceeds these amounts a separate room or compartment, or better still, a separate building should be used.

No open flame should be used for heating or lighting. Heating - where provided - should be by hot water or steam only. Forced draught hot air heating systems with inlet and outlet ducts are also inadvisable. Radiant heaters and unit heaters with motor driven fans are also a source of danger should gas leaks cause an accumulation of a combustible gas/air mixture.

No smoking, matches or open lights should be allowed in the storage place.

Acetylene cylinders should be stored as well as handled and used in the upright position.

Should a leak develop, which cannot be stopped by tightening a valve or gland nut, remove that cylinder to the open air, chalk 'LEAKING' on it, tie a tag to the neck indicating the type of leak, and advise the supplier accordingly.

General

Encourage operators to refer to gases by their proper names and not to use the words 'gas' or 'air'.

Never allow oxygen to be used as a substitute for compressed air, for example for blowing out electric motors, tanks or pipelines, operating pneumatic tools, dusting clothing, starting engines, as a means of ventilation or for creating pressure.

Do not allow the colour or markings of gas cylinders to be altered or valve connections to be tampered with.

No attempt should be made to mix gases in a cylinder or to decant gas from one cylinder to another.

Never use gases with any type of equipment without fitting a proper pressure reducing valve or regulator to the cylinder valve.

ACETYLENE GENERATORS

Because of the dangerous character of acetylene and the risk of explosion with even small leaks or escapes of gas, several safety rules MUST be observed in the installation and use of acetylene generators. It is essential for operators to study, and become thoroughly acquainted with, the installation and operation instructions provided by the generator makers and no one should be allowed to have charge of such an installation unless they are judged to be competent.

Buildings

Stationary generators should preferably be installed in a separate building apart from the workshop and having no window or door connected with it. The generator house should be constructed of non-combustible material.

Oxygen cylinders may be stored in the acetylene generator house, but the storage place must be separated from the generator room by a partition of non-combustible material extending from floor to roof or ceiling with a gas-tight joint.

Where the installation of a generator is allowed in a building which is also used as a workshop or for some similar purpose, the generator room should be an entirely separate compartment of ample size. The walls or partitions, also the

floor and ceiling, should be of non-combustible material. Openings should be protected by an approved type of fire door. Windows should be of the wired glass type on metal frames.

In any generator room or building, exit doors should open outward. Ample through ventilation should be provided. Heating - if used - should be by hot water or steam. No electric radiators, radiant heaters or open flames should be allowed under any circumstances. Windows should enable all operations to be carried out in daylight. If electric lighting is provided the bulbs should be in gas tight and flame proof fittings, all wiring must be in screwed conduit, and switches should preferably be outside the building. The whole electrical installation may in fact be kept outside the building by arranging for the lights to illuminate the interior through wired glass panels or windows.

Installation

Generators should be installed in accordance with the maker's instructions and the requisite safety precautions must be observed. The following points in particular should have attention:

The water supply should not be directly coupled to the generator unless the generator is provided with a visible overflow or overfilling prevention device. Alternatively the water supply should discharge visibly into a filling funnel on the generator.

Drains should not be directly coupled to the generator but the drain tap should discharge into an open drain channel leading to the sludge pit.

Vent pipes must be carried full size without intervening valves to the outside of the building. They should terminate as far as possible from windows, chimneys or other openings or positions likely to be a source of danger. The outlet should be fitted with a bend or hood so as to prevent any possibility of obstruction.

Never use copper pipes or fittings with a high copper content for the distribution of acetylene, since copper and acetylene unite to form unstable compounds of an explosive nature

Operation

Generators should be operated only by approved operators who are thoroughly conversant with the mechanism of the generator. A copy of the maker's instructions must be kept and studied by the operator and the appropriate wall charts prominently displayed in the generator house.

Charging and cleaning operations should be carried out in daylight as far as possible. To enable this to be done, the size of the generator should be carefully considered in relation to the gas consumption.

No attempt should be made to force a generator to produce gas at a greater rate or higher pressure than that for which it was designed.

Relief valves should be operated regularly to make sure that they are functioning correctly.

Should carbide lodge in the feed hopper or chute, or the feed mechanism jam at any time, no metal tool should be used to effect clearance. Use only a wooden stick.

Hydraulic seals should be protected against freezing in cold weather otherwise they will provide no protection. The water level in the seal should be checked periodically.

Portable Generators

Do not use portable generators within ten feet of combustible material. Charging and cleaning should be done in the open air. When charged with carbide do not move by crane or derrick.

Miscellaneous Precautions

Every possible precaution should be taken to prevent the accumulation of acetylene-air mixtures, the accidental generation of acetylene or the creation of a spark. If a generator is not in use and the hopper contains carbide the water chamber should be kept filled to the correct level.

Do not ram carbide charges.

The interior of generators should be inspected periodically; and solid residue should be removed, and repairs carried out if required.

Whenever repairs are to be made the carbide charge should be removed, and also, if possible, the feed mechanism. The generator should also be disconnected from any piping system. All acetylene should be expelled by flooding the generator shell with water.

Thaw frozen generators or hydraulic seals with warm water. Do not use flames or hot metal.

When repairs involving heat are necessary, they should preferably be made out-of-doors.

Calcium Carbide

Calcium carbide in contact with moisture will produce acetylene gas with the risk of explosion and fire. Therefore some care is necessary in the storage and use of carbide containers.

Containers should be stored in a dry, fire-resisting building having similar construction provisions to those already given on pages 7.4 and 7.5 for acetylene generator houses.

Care should be taken in handling drums to avoid puncturing them. Drums should not be rolled over wet surfaces in case there is a puncture through which moisture could enter.

Open containers carefully in order to avoid striking a spark. A hammer and chisel must not be used; the so-called 'sparkless tools' are best but even they must be used with care.

Gas Distribution Pipelines

Under no circumstances should oxygen or any fuel gas piping be run in the same trench with oil pipes or electric cables.

Oxygen and fuel gas lines should be painted distinctive colours in order to avoid mistakes or confusion.

Use only steel or wrought iron pipe for acetylene. (See also page 7.5.)

Pipeline distribution systems for acetylene must be protected from flash back by suitable safety devices. Large systems should be sectionalized and individually protected. Each outlet point on the pipeline should be provided with either a hydraulic seal or a suitable pressure regulator according to the type of installation.

GAS WELDING AND CUTTING EQUIPMENT

Oxygen and acetylene regulators and the gas hose connections on torches have different screw threads in order to prevent interchangeability. This is important and no attempt should be made to adapt or alter the fittings since acetylene and liquified petroleum gas pressure regulators in particular are not suitable for use on oxygen cylinders.

Assembling the Equipment

Care should be taken to make sure that the connections on the oxygen and acetylene cylinders are clean and undamaged before attaching regulators. The valve must be momentarily opened and closed ('cracked') in order to clear out any dirt in the socket or orifice.

After the pressure regulators are attached to the cylinders, the cylinder valve should be opened very slowly, otherwise the internal mechanism of the regulator may be strained or damaged.

Operators should not stand in front of pressure gauges while the cylinder valve is being opened.

Hose

In order to minimize the possibility of mistakes at any time, red hose should be used for acetylene and other fuel gases; green hose should be used for oxygen.

Make sure that hose is securely clipped to the connecting fitting. The use of a push on, and wire bound fitment is not good practice.

Hose* deteriorates rapidly if carelessly used; therefore, operators should be warned against pulling hose over sharp edges, allowing it to lie on hot metal, oil or grease, or where it will be burnt by sparks. Where hose must be laid across a pathway used by persons or vehicles, it should be covered with inverted angle iron, or protection boards may be laid on each side of the hose to prevent it from being crushed or cut. Hose should not be sharply bent as this may rupture the canvas ply.

Old hose is a source of danger, owing to its liability to hardening and cracking, and should be discarded.

* applies also to electric cable.

A backfire may cause the hose to burn and char internally. If so, this will be indicated by the hose becoming hot and under such circumstances it should be discarded as there may be some doubt as to its reliability.

ARC WELDING EQUIPMENT

Loose connections are a source of danger and loss of power. Therefore all cable connections should be securely fastened. Particular attention should be paid to the electrode holder connection and the ground lead connection to the work or work table.

Cables should be capable of carrying the required amperage without overheating. The following are recommended cable sizes for various amperages:-

Amperage	Cable Size
150	No. 3
200	No. 2
300	No. 1/0
400	No. 2/0
500	No. 2/0
600	No. 3/0

Where the cable length exceeds 50 feet, a larger size should be used.

Insulated connectors capable of carrying the required amperage should be used for connecting lengths of cable. If cable lugs are used for this purpose they must be completely insulated.

Cable should be kept drv. free from oil and grease and protected from damage (see "Hose", page 7.8), and inspected periodically for damaged or perished insulation.

Never use electrical conduits or pipes containing gases or inflammable liquids for a ground return circuit.

Portable welding plants used in the open should be protected from the weather. Care must be taken to see that the electric supply, or input lines (high voltage) do not become entangled with the welding cables, or are not left in such a way that they may be cut, exposing the high voltage conductors. Long cables should be supported overhead, but if this is not possible, cables laid on the ground should be protected as suggested for gas hoses (see "Hose", page 7.8). Where such

precautions are not practicable due to the continual movement of generators, it is recommended that the input lines be kept to a minimum length - not to exceed 50 feet.

Some care is necessary in paralleling transformer welders, and reference should be made to Lesson 4, page 24 where the matter was dealt with. See page 7.16 for notes on the prevention of electric shock.

THE HEALTH AND SAFETY OF THE OPERATOR

General

Although welding and cutting operations are not particularly hazardous in general, and are certainly not unhealthy for the operator, sundry health and safety precautions are essential and their degree of importance depends on the type of work and/or the conditions under which it is being done. The normal risk of accident to both himself and others is of course increased by the fact that the operator's vision of, and sensitivity to, his surroundings is limited by his goggles or head shield and his concentration on the operation in hand.

Where welders work on platforms, scaffolds or in similar elevated positions, provision should be made to prevent them from falling. When working in the open, wind screens are desirable. Gas cylinders and other equipment should also be secured so that there is no danger of them falling or of being knocked over. The area under such positions should be clear of inflammable materials and should be roped off to protect unsuspecting persons from danger. It may be desirable to provide an attendant whose duty it will be to see that gas hoses or cables do not become fouled and to warn the operator of any likely danger.

Work that is to be heated or welded should never be laid on a concrete floor, because when sufficiently heated, a portion of the concrete may spall and fly with possible injury to the operator.

Special safety precautions are necessary when work is being carried out in confined spaces. Work undertaken in or on oil and gas tanks is also considered particularly hazardous. These precautions are dealt with on pages 7.15 and 7.16.

Clothing

The operator's clothing and overalls should not be of

an inflammable material or be liable to catch sparks which may smoulder and cause a fire either during the operation or when the clothing has been discarded after the work is finished. Woollen clothing is less inflammable than cotton. All clothing should be free from oil or grease. Rolled up sleeves, trouser cuffs, pockets and low cut shoes should be avoided. Clothing may be flameproofed, but washing with water usually destroys the proofing and articles must be reproofed after laundering. Flameproofing dips for overalls may be purchased. In some cases cleaning concerns will flameproof materials or alternatively a flameproofing dip may be made up as follows:

Prepare one solution of 3/4 lb. of sodium stannate in 1 gallon of water and another of 1/4 lb. of ammonium sulphate in 1 gallon of water. Dip the article in the first solution and wring out, then dip in second solution, wring out thoroughly and dry. Do not wash in water.

Operators should wear gauntlet gloves, and leather aprons are also recommended. For particularly heavy or hot work, fire resisting leggings and/or boots may be desirable. In cold weather leather jackets provide warmth with fire protection. Safety shoes or boots are desirable.

Eye and Skin Protection

The welding arc gives off ultra-violet and infra-red rays in addition to visible light. It is these rays, which are also contained in sunlight, that cause skin burns, and a similar result occurs upon exposure to the arc.

The welding helmet provides protection for the face, but shirt sleeves, cuffs and collars must be kept buttoned. Light, summer weight shirts do not offer enough protection against this form of 'sunburn'.

Because forty feet is the shortest distance from which the arc should be seen by the naked eye, the provision of suitable eye protection by means of goggles for gas welding and cutting, and face or head shields for arc welding is an absolute necessity for the operator.

There are, however, a few details in this connection which are not always sufficiently appreciated:

The glass used in goggles, face masks or head shields should be definitely suitable for such work. Ordinary glass - simply because it happens to be coloured - is usually not suit-

able. Special glass for these operations is obtainable in various shades. This glass absorbs most of the harmful ultra-violet and infra-red rays as well as a large amount of visible light. Lenses have been classified into shades of varying density or darkness. Suitable choice of shade may have a considerable effect on the operator's comfort and vision, and the object must be to select a shade which will eliminate glare but allow the work point to be seen distinctly. It is, therefore, obvious that no one shade of glass can suit all types of welding and cutting operations. Shades 10 and 12 are usually the most suitable for arc welding operations. Shade 12 is particularly suitable for use with large electrodes and high currents.

The shaded lens must be protected from spatter by clear cover glass. This clear glass must be kept clean and when it becomes badly pitted it should be replaced.

Where the work permits, arc welders should work in a booth, or within an area enclosed by suitable screens in order to protect fellow workers and others from the arc rays. While most people know that it is harmful to look directly at arc welding with the naked eye, it is not always known that considerable discomfort can be caused by side flashes and reflections.

Where several welders work within an enclosed space, protection from side flashes and reflection is also important. This may be achieved by the provision of suitable goggles which may be worn in addition to the head or face shield. Other workers in the same area should be similarly equipped.

If welding is done in the open shop, it is usually possible to provide screens (flame proofed canvas, metal or plywood sheets) to protect other workers from the arc rays, and even overhead crane drivers may need goggle protection. Walls in the welding area and the inside of screens should be painted with a non-reflecting colour.

Goggles or a face shield should be worn by operators when chipping or grinding welds, to protect the eyes from flying particles.

Each operator should have his own shield or goggles which should be sterilized occasionally by exposure to live steam for five minutes, or immersion in boiling water for five minutes. Should it be necessary to make a transfer from one operator to another, they should be cleaned and sterilized before being used.

Treatment of Eye Burn (Arc Eye)

The symptoms of flashed eyes are a pronounced irritation under the eyelids, a feeling as if there were "sand in the eyes". These symptoms usually develop several hours after exposure, and thus, frequently after the worker has left the plant, and sometimes in places where no doctor is readily available. No permanent after-effects result from eyeburn, but haphazard or careless treatment of eyeburn and flashed eyes is most inadvisable as there have been cases of permanent eye injury resulting therefrom. Eye treatment by a nurse or doctor is in all cases preferable but where this is not readily available the following first-aid methods have been found effective if carried out under clean and antiseptic conditions:-

For mild eye burns or flashes a few drops of sterile oil (olive oil may be used) may be placed in the eyes and aspirin used to relieve the pain. Alternatively, three drops of a 10% solution of argyrol, or a small quantity of butyn (in drop or salve form) will be found to help. Bandages, or slightly tinted glasses (shade 3) may be worn to provide additional relief. Complete rest for the eyes is important.

For severe burns there are a number of preparations available, among them being Holocaine and Epinephrin ointment; Chloromycetin, Aureomycin, and other antibiotic compounds. These should be used only on the advice of a doctor, who can prescribe in advance for the first-aid kit.

For all severe cases a physician should be consulted as soon as possible after exposure, to ensure that the eyes have not become infected, and to ascertain whether further treatment is necessary.

Ventilation

Generally, for arc welders working on steel with normal electrodes in large workshops provided with normal ventilation, no extra ventilation is required on account of welding. On the other hand, in small workshops the matter needs some attention in proportion to the number of welders and size of electrode generally employed. Otherwise the smoke and fume concentration, although not actually injurious, is liable to cause discomfort. The following points should, therefore, have attention:

Screens should be arranged so that they do not restrict ventilation. Cubicles will require special ventilation provision.

Roof or wall fans should ensure about four air changes per hour.

For welding or cutting operations on non-ferrous or galvanized metals extra ventilation will be required. Under some circumstances it may be necessary to provide the operator with a respirator or mask of suitable type. The important point is that the closer the operator is to the job and the more confined the space, the greater is the danger of fume inhalation.

Exposure to zinc fumes arising from galvanized iron may result in metal fume fever, commonly called "zinc chills". It usually develops a few hours after exposure and lasts less than 24 hours. It is self-limiting, without complications or after effects. Daily exposure usually results in an immunity which lasts as long as such regular exposure continues.

Cadmium and lead fumes (e.g. from rust proof coatings, lead coverings or lead paint) are definitely dangerous and special precautions must be taken. While general shop ventilation must be provided, the operator must, in addition, be provided with an air-line respirator, hose mask or filter type respirator approved for use with these fumes.

When an operator is working in a confined space such as a tank or boiler or in small badly ventilated ship compartments, the provision of adequate fan ventilation is essential. The incoming air must be fresh and clean. Suggested rates of air flow for a single welder using electrodes of the following sizes are:-

1/8" electrode . . . . 250 cft/m
3/16" electrode . . . . 400 cft/m
1/4" electrode . . . . 700 cft/m

The air flow should be so arranged that it is across the weld, i.e. between the welder and the work. Where an exhaust hose is used it should be placed about 8 inches from the job. If placed too close undesirable oxidation of the weld may result.

Where the provision of fan ventilation is impossible, air-line respirators or hose masks may be used.

Working in Confined Spaces

Work in confined spaces calls for extra safety measures which must be rigidly adhered to. Ventilation requirements as already dealt with, and the flameproofing of clothes as outlined, must also have attention.

If there is any possibility of the space having contained oil, paints, gas or substances likely to give off inflammable, explosive or noxious vapours, cleaning should be done as outlined under "Empty Vessels". page 7.16.

The means of exit from the space must allow for easy escape in the case of emergency. It should also allow for the removal of an operator by means of a safety harness should he be overcome by fumes or fire.

An attendant should be stationed outside the space and his duty must be to keep the operator in view at all times and to attend to the equipment outside the space. He should not allow the exit to be obstructed at any time, and should see that the safety harness, rope, air or gas hose and/or cable do not become fouled.

Welding or cutting equipment, apart from the torch or electrode holder, gas hoses or cable, must be left outside the space.

Any risk of the accumulation of explosive gas mixtures must be avoided; therefore, when gas equipment is employed, particular attention must be paid to the gas tightness of the hoses and their connections, as well as the torch valves. Torches should be lighted and adjusted outside the space.

When arc welding equipment is used the possibility of shock must be avoided. Therefore, connections should be inspected for both electrical insulation and tightness. The electrode holder should be completely insulated so that accidental contact with metal parts of the structure cannot be made. Should it be necessary to take a portable electric lamp into the space, this fitting should be of an approved all-insulated type.

Care should be taken not to allow gas hoses or cable to lie on hot metal or to be chafed on sharp edges.

Whenever work is stopped and the operator leaves the space, all welding or cutting equipment should also be removed.

Fire extinguishing and first aid equipment should be available and ready for use at a moment's notice; the attendant should know how to render any such assistance that may be required, and provision should be made for summoning help should it be needed.

Empty Vessels

It is sometimes found necessary to weld or cut on or in vessels which may have contained oils or paints or other substances likely to give off explosive or inflammable vapours. Even if such vessels are considered to be empty, and have been for some time, it must be remembered that residues are likely to remain for an indefinite period as a thin surface film, or may be trapped in joints or riveted laps. These residues will be evaporated by the heat of the process, with the possibility of forming an accumulation of dangerous vapours.

The only really effective way of cleaning such vessels is to use hot steam so that the heat and scouring action of the steam evaporates and clears out the residues. Washing out with water is quite useless. Steaming should be carried on until there is no doubt whatever that all residues have been evaporated and/or removed.

Containers which have held heavy oils and grease should be cleaned with a hot water solution of caustic soda and trisodium phosphate, or trisodium phosphate alone. The vessel should first be heated with steam (as above) to free residues from crevices. Cleaning should be carried on until no further sludge is produced.

Containers which can be manipulated should be arranged so that the welding or cutting point is uppermost and the remainder of the space should be filled with water to the highest possible level. Plugs or covers above the work point should be removed in order to vent hot air.

Electric Shock

Under normal working conditions the possibility of an operator receiving a fatal electric shock from arc welding equipment is very remote. It should however be appreciated that a shock, although not itself fatal, may dislodge an operator from his working position with the possibility of serious results.

It is therefore very important to ensure that carelessness, ignorance, lack of supervision or foresight or neglected equipment does not create dangerous situations.

The first step is to see that the framework of the machine is properly grounded in order to provide protection against electrical failure on the input (or high voltage) side. Operators should also be warned not to interfere with the motor starter connections or its power supply lines.

Dampness in any form greatly increases the risk of shock should any part of the body make contact with an electric current. Dangerous situations may therefore be created by moist gloves or clothing, damp floors or humid surroundings. Operators should be warned against touching an electrode or holder with any unprotected part of the body or any part covered with wet or damp clothing. When working on damp or wet floors the use of rubber boots is advisable. Particular care is obviously necessary when welding is being done in confined spaces; in such cases the use of an all insulated type of electrode holder is essential. When not in use, electrode stubs should be removed from the holder, and the holder placed or hung in such a position that it will be completely insulated.

Maintenance of good insulation of the cables, connections and electrode holders is most important. The cable should be examined periodically especially where it enters the electrode holder, at which point the insulation is subjected to excessive deterioration due to the conducted heat and flexing of the cable. At all times the operator should avoid damaging the insulation by observing the recommendations given under "Hose" on page 7.8.

Should an operator receive a severe electric shock or burn, a doctor should be summoned without delay. Should an operator sustain a fall, he should be made as comfortable as possible, but moved only under medical supervision.

INERT GAS

In addition to the precautions to be observed in other arc welding processes, there are certain special hazards which must be taken into account when welding with either tungsten or consumable electrode using helium or argon, mixtures of helium and argon or mixtures of argon with oxygen.

The hazards considered important at present arise from Trichloroethylene Decomposition, Radiant Energy and Metal Fumes.

Trichloroethylene Decomposition

(a) A warning of the danger of trichloroethylene decomposition should be given, with the recommendation that degreasers or other sources of trichloroethylene vapors should be so located that no such vapor will reach the welding operations.

(b) As an additional precaution, personnel should be advised to become acquainted with the characteristic, objectionable, irritating odor accompanying this decomposition. (This may be done by opening a small container of trichloroethylene at a distance of two to three feet from the arc.) Welding should be stopped when this characteristic odor is noticed until the source of trichloroethylene vapor can be determined and controlled.

Radiant Energy

Radiant energy, particularly in the ultraviolet range, presents a far greater intensity during inert-gas welding than during shielded arc welding (with covered electrodes). This hazard is of significance to the bare skin and to the unprotected eyes. The greater intensity of the ultraviolet also causes rapid disintegration of cotton clothing.

Metal Fumes

As with any welding process inhalation of the fumes produced in inert-gas metal-arc welding, particularly while using the consumable electrode method, may cause metal fume fever where metals that cause metal fume fever are involved.

FIRE PREVENTION

Owing to the high temperature involved in welding and cutting processes, and the almost inevitable production of hot metal accompanied by sparks, it is most essential that fire prevention precautions be rigorously observed whenever these operations are performed. Obviously, such precautions are particularly necessary when the work is carried out amid combustible surroundings. In the average workshop where

this type of work is regularly done, fire precautions will be, or should be, part of the normal safety routine. Special care is, however, necessary when portable equipment is employed in places where welding or cutting operations are unusual. Therefore, although the following points are applicable to all types of welding or cutting operations, they should have particular attention in the case of emergency operations or when portable equipment is used.

Welding or cutting should never be permitted where explosive gases or vapours, inflammable liquids, or highly combustible materials are in the near vicinity.

Where normally combustible materials such as wood, oily rags, cotton waste, etc., are present, these materials should be removed well out of the range of heat and sparks. Remember that sparks may fly or roll as far as 30 feet from a cutting operation.

Combustible materials, also wooden floors, walls, and other parts of a structure which cannot be removed, should be suitably protected by steel or asbestos sheeting or by soaking with water. Do not use tarpaulins. Remember that sparks may lodge in crevices and cracks and start smouldering.

Where there are openings or large cracks in floors or walls, care should be taken to ascertain that any sparks which may pass through the openings will not start a fire among combustible materials. Apply the precautions given above to adjacent rooms and/or the floor below.

Electrode stubs may be a source of fire risk if thrown onto a wooden floor or dropped from a structure onto combustible material beneath.

Make sure that oxygen and acetylene hoses do not lie on hot metal or in the way of hot slag or sparks. (See also "Hose" on page 7.8.)

Loose electrical connections are liable to be a source of fire risk in that they will cause overheating at the joint or even possibly a spark.

Keep fire extinguishing means at hand and ready for immediate use. When work has been done in the vicinity of combustible materials, a man should stay in attendance for at least half an hour after the work is finished to ensure that no fires break out, and he should inspect the site thoroughly before leaving.

REFERENCES

Some of the principal sources of safety information in Canada and the U.S.A. are given below:

1. Code for Safety in Electric and Gas Welding and Cutting Operations (1st Edition) - CSA W117-1952*.

2. Code for Head and Eye Protection - CSA Z94-1948*.

3. The Factory, Shop and Office Building Act - Department of Labour, Parliament Buildings, Toronto, Ont.

4. Safety Code and Regulations Governing the Construction Industry - Construction Safety Association of Ontario, 55 York Street, Toronto 1.

5. Preventing Welding and Cutting Fires - The National Fire Protection Association, Boston, Mass., U.S.A.

6. The Safe Handling of Compressed Gases - Compressed Gas Manufacturers Association Inc., 11 West 42nd Street, New York, N.Y., U.S.A.

7. Gas Systems for Welding and Cutting - N.B.F.U. Pamphlet No. 51 with amendments August 1951.

8. Welding Instructions..for Shipyard Welding - U.S. Maritime Commission Washington, D.C., U.S.A.

9. Safe Practices for Oxy-Acetylene Welding and Cutting Equipment - International Acetylene Association, 30 East 42nd St., New York 17, N.Y., U.S.A.

10. Safety in Electric and Gas Welding and Cutting - The American Standards Association, 70 East 45th St., New York 17, N.Y., U.S.A.

11. The Publications of The National Safety Council, Chicago, Ill., U.S.A.

12. Safe Practices for Welding and Cutting Containers That Have Held Combustibles, A6.0-52 - American Welding Society, 33 West 39th St., New York 18, N.Y., U.S.A.

13. Recommended Safe Practices for Inert-Gas Metal-Arc Welding, A6.1-55 American Welding Society, 33 West 39th St., New York 18, N.Y., U.S.A.

14. Health Protection in Welding - Industrial Health Section, Metropolitan Life Insurance Co., New York, N.Y., U.S.A. and Ottawa, Canada.

15. The Welding Handbook (3rd Edition) - American Welding Society, 33 West 39th Street, New York 18, N.Y., U.S.A.

16. Air Cooled Transformers (dry type) - CSA C22.2 No. 47 - 1940*.

17. Inside Wiring Rules (5th Edition) - CSA C.22.1-1947*.

* from the Canadian Standards Association, 235 Montreal Road, Ottawa, Ont.